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Victor H. Pellicione, Joseph Popolo, et. al.

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The objective of this study was to develop guidelines for the application of Environmental Stress Screening (ESS) to field inventory hardware. Methods were developed for the selection of equipments for ESS application which offer significant potential for operational readiness improvement and life cycle cost reduction. A 2:1 reduction in field removal/maintenance action rates was found for hardware subjected to ESS when compared against identical hardware not subjected to ESS. A large percentage of the improvement in the ESS hardware was found to be traceable to reductions in Cannot Duplicate (CND) and Retest OK (RTOK) rates. LRU's, identified by serial number, which demonstrate recurring removal histories much higher than population norms, were found to make excellent candidates for ESS. Tradeoffs between screening implementation costs (facilities, repair) and downstream logistics support savings, over the remaining product life, were also found to be critical to the ESS candidate selection process. Recommended random vibration and temperature cycling screening regimens are also included in the guidelines.

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PREFACE

This final technical report was prepared by Grumman Aircraft Systems Division (ASD), Reliability, Maintainability, and Safety Section, Bethpage, New York, under contract F30602-85-C-0103 for Rome Air Development Center (RADC). Mr. Eugene Fiorentino was the project engineer for RADC.

The effort described was accomplished during the period from September 1985 through May 1987.

Under the direction of principal engineer Mr. Joe Popolo, the Grumman study team included project engineer, Victor Pellicione, technical staff; Jeff Triolo, Murry Rosenfeld, Brian Farrell, Karl Rehm, and Arlene Apollo.

We wish to further acknowledge the field interface support of Mr. John "Dusty" Rhoades of Grumman's Field Marketing Department, and the cooperation of the numerous Air Force logistics centers and operational facilities visited during the study including:

- Wright-Patterson AFLC
  Wright-Patterson AFB, Ohio
- Warner Robins, ALC
  Robins, AFB, Georgia
- Oklahoma City, ALC
  Tinker AFB, Oklahoma
- Sacramento, ALC
  McClellan AFB, California
- Langley TAC/HQ
  Langley AFB, Virginia.

EXECUTIVE SUMMARY

Environmental Stress Screening (ESS) is currently being used extensively, by electronic equipment manufacturers, as a means for effectively removing process induced, workmanship and part defects from their products. Much of the current Air Force electronic equipment inventory has not had exposure to ESS. Questions and issues regarding the application of ESS to field inventory hardware are addressed in this study. Guidelines are developed for cost-effectively applying ESS to field inventory hardware.

Electronic equipment currently in the operational inventory contain residual latent defects which were introduced into the hardware, either during the original manufacturing process or through prior maintenance handling and use operations. Latent defects are weaknesses or flaws in parts and connections which exhibit much higher failure rates during early operational life than reliability design goals would indicate. Such defects manifest as functional intermittents resulting in excessive Cannot Duplicate (CND) and Retest OK (RTOK) actions, as well as hard failures. Latent defects are in effect usage and process induced and not functions of the inherent design life. It is highly likely that selective application of ESS to such equipment, under properly controlled conditions, will result in significant improvements in field reliability.

Field maintenance data, representing over 10 years of field operational and maintenance history, were used to assess the effectiveness of ESS in improving field reliability. Five case histories of electronic LRUs of various complexity and design were compiled and analyzed. The LRU case history populations contained some LRUs which were exposed to ESS in the manufacturer's plant and others which were not. Comparison of the ESS vs non-ESS populations provided the means for assessing the effectiveness of ESS, under actual field stress conditions of operation and use. The improvements achieved in terms of Mean Flight Hours Between Removal (MFHBR) of the ESS versus the non-ESS populations, are shown in Table 1.

TABLE 1

RELIABILITY IMPROVEMENT - ESS vs NON-ESS EQUIPMENT

EQUIPMENT	NON-ESS MFHBR	ESS MFHBR	% IMPROVEMENT
A	32	70	119
B	66	127	92
C	83	149	80
D	92	278	202
E	570	1110	95

The data clearly demonstrate the benefits of ESS.

- o ESS of new hardware (i.e. at a manufacturer's facility) is effective.
- o Reduction of overall removal rates results in improved MFHBR on the order of 2:1 across the board.

Economic analysis of the case history data indicate that significant savings in logistic support cost, ranging in the millions of dollars, were realized, as shown in Table 2.

TABLE 2

LOGISTICS SUPPORT COST SAVINGS - ESS vs NON-ESS EQUIPMENT

				TOTAL LSC			LSC PER LRU	
LRU	AVG UNIT $	AVG MFHBR W/O ESS	AVG MFHBR W ESS	DIRECT LSC W/O ESS $ M	DIRECT LSC W ESS $ M	DELTA SAVINGS $ M	DELTA SAVINGS $ K	SAVINGS AS A % OF LRU UNIT COST
A	312,000	32	70	151.7	57.7	94.0	261.1	84
B	82,036	66	127	26.4	11.5	14.9	41.3	50
C	162,932	83	149	46.0	25.1	20.9	58.1	36
D	26,160	92	278	9.2	5.5	3.7	10.3	39
E	55,217	570	1110	3.0	1.8	1.2	4.2	8

NOTES:
- AF LSC MODEL, VERSION 1.1, JANUARY 1979; OPERATIONAL DATA IN APPENDIX A
- 1985 DOLLARS
- SERVICE LIFE: 15 YEARS

The benefits to be derived from screening inventory hardware, potentially, can be at least the same or better than that illustrated by the ESS case history data. Several important differences should, however, be noted. With inventory hardware, actual field reliability performance can be observed and used in selecting candidates with the best potential for improvement. Therefore, 100% screening, as is the case for factory applied ESS, is not necessary nor cost-effective. In addition, application of ESS in the field must be performed in a non-homogeneous product control environment. Service life build-up and repeated repair of field equipment will have affected lot homogeneity as well as identifiable configuration controls. Screen implementation and inventory management costs will also exact its toll on any logistics cost savings that may be realized. For these reasons, a field ESS program must be defined that will identify, select, and optimally screen only those equipments and levels of assembly which will provide the most potential for reducing the aggregate removal rates, within realistic cost constraints and the shortest time practical.

Comparison of the ESS and non-ESS case history data provide several significant findings which form the basis for the guideline development. The scope of the study data base is shown in Table 3.

TABLE 3

ESS VS NON-ESS CASE HISTORY DATA BASE

	NON-ESS						ESS					
EQUIPMENT	TOTAL NO. A/C REPORTING	TOTAL NO. FLIGHT HRS	YRS OPERATION	TOTAL NO. UNITS REPORTING (SER NO. LRUs)	TOTAL NO. REMOVALS FOR CAUSE	AVG. NO. REMOVALS/ UNIT	TOTAL NO. A/C REPORTING	TOTAL NO. FLIGHT HRS	YRS OPERATION	TOTAL NO. UNITS REPORTING (SER NO. LRUs)	TOTAL NO. REMOVALS FOR CAUSE	AVG. NO. REMOVALS/ UNIT
A	222	370,437	11	1106	11695	10.5	114	120,140	4	587	1718	2.9
B	222	370,437	11	970	5631	5.8	114	120,140	4	453	948	2.1
C	222	370,437	11	849	4445	5.2	114	120,140	4	432	805	1.9
D	222	370,437	11	1029	4038	3.9	114	120,140	4	235	433	1.5
E	47	126,667	6	377	1330	3.5	22	53,157	5	156	287	1.8

The findings include:

- Level of Assembly Testing - The LRU is defined as the focal point for hardware selection and screening. In a field scenario, it is the collective vehicle for all quality defects. Screening the LRU subjects the entire population of assemblies and parts to the screen. The LRU provides:
  - Measurable removal rates obtained under actual operating stress conditions.
  - A means for monitoring and selecting individual units by serial number.
  - The basis for "Bad Actor" hardware selection.

  By contrast, there is no significant maintenance improvement or cost benefit that can be justified by indiscriminate screening of SRUs and lower levels of assembly. One-at-a-time repair by replacement with screened lower levels of assembly has little impact on the aggregate LRU defect population. To have any impact at all, the lower level of assembly must make a significant contribution to the LRU removal rate, and the removal rate of the LRU must be significantly high in order to have the greatest impact on operational readiness.

- Hardware Selection - In the selection process, high contributor removal rates will provide the prioritization for initial LRU selection. "Bad Actor" selection offers the best potential for attacking the highest percentage of ESS sensitive defectives, within a small percentage of the total LRU population. The serialization of LRUs and their traceability provides a process control mechanism for identifying and determining the distribution of removals by individual unit. Serial number tracking enables identification of specific units ("Bad Actors") having maintenance action/removal frequencies much higher than the operational norms. In the case histories studied, Bad Actor ranks constituted more than 70% of the removals in less than 30% of the units. For the non-ESS equipment, more than 50% of the removals were false alarms or cannot duplicate actions which are known to be highly correlated to ESS detectable intermittent type failures.

- Generic ESS - In the implementation of the formal ESS test program at the ALC, generic ESS profiles for rapid thermal cycles and random vibration are defined and recommended. In each of the case histories generic practices were used. Generic screening profiles will simplify ESS testing operations,

reduce ESS set-up costs and minimize ESS training requirements. The generic guidelines are typical of those defined by MIL-STD-2164 (EC) and NAVMAT P-9492. In addition, guidelines for tailoring are provided for those cases where the equipment may not have been designed to function within the defined random vibration or rapid thermal cycling environments. Use of the techniques will minimize the potential for overstressing the equipment when generic ESS levels are applied.

- o <u>ESS Economics</u> - The economics of field ESS dictate that the optimal Return-on Investment (ROI, nominally 33 1/3%) is achieved most consistently by screening only a select minimum number of units. Bad Actor selection offers the best opportunity to achieve this goal. To minimize the cost benefit risk:
  - Selected units should be high removal rate contributors, coupled with high unit cost. This will maximize the logistics support cost savings.
  - Screen durations should be reduced, where possible, to minimize screen/test facility loading and lower screen implementation costs.
  - Lower levels of assembly screening (SRU) should demonstrate significant improvement potential in LRU removal rate, nominally greater than 25%, to ensure effective ROI payoff.
  - Screening of aged or low removal rate equipment should always be justified on a ROI basis.

In order to assist cognizant Air Force Logistic Center (ALC) and responsible item managers in planning and implementing an ESS program for field inventoried equipment, guidelines are provided herein as Appendix C. The guidelines provide the methodology for:

1. <u>Equipment Selection</u> - Based on established equipment field maintenance histories.
2. <u>Selection Criteria</u> - Designed to minimize the quantity of equipment selected for screening and to maximize improvement in operational readiness.
3. <u>Test Profile Development</u> - Designed to exercise established and proven temperature and vibration screening levels and durations within equipment design qualification limits and operational capability.
4. <u>Economic Selection</u> - Designed to minimize cost of testing and to maximize logistics support cost savings within realistic Return on Investment (ROI) goals.

Future study efforts should focus on validating, refining and standardizing the approach. We recommend that:

- o Several pilot study projects be undertaken on inventoried equipment to thoroughly evaluate the guideline methodology.
- o Bad Actor selection offers the opportunity to select a small number of LRUs, which minimize the impact on LRU availability and system readiness, and yet effectively reduces a high percentage of the ESS sensitive removal rate. The pilot projects should be used to validate and refine the selection criteria, screening and cost benefit methodology contained in the guideline.
- o Air Force field maintenance data and performance monitoring systems should be modified, where necessary, to enable serial number tracking of the hardware (LRUs and SRUs) and to facilitate application of ESS to all high removal rate products in the inventory.

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Appendices

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ILLUSTRATIONS (contd)

TABLES

1 - INTRODUCTION

Application of Environmental Stress Screening (ESS) during manufacture of electronic equipment is attaining widespread use as the means for reducing the effects of manufacturing, quality, and system process defects on field performance. These defects, commonly termed "latent defects", are traceable to poor workmanship, out-of-control processes, or defective parts and assembly. Analyses of field data have shown that latent defects can have a severe impact on the excessive removal rates of hardware in the field, resulting in reduced field reliability and weapon system readiness.

Further, hardware subjected to many repair cycles or to field modification and handling may, as a result of these actions, have additional defects induced which exacerbate the hardware's degradation. These defects can be introduced by spare parts and lower levels of assembly which have not been previously screened, and by poor workmanship and maintenance practices during repair and handling. The defects manifest as excessive removal rates caused by: functional intermittents which precipitate false alarm (or no defect found) actions, excessive tolerance and functional checks, as well as repairs due to broken, loose, or mismatched components.

Hardware which has not had ESS exposure can exhibit much higher removal rates during early or even sustained operational life than predicted or demonstrated reliability baseline values would indicate. Since defects are in effect attributes of specific equipments and not a function of the inherent design life, there is the possibility that the application of ESS to such equipment, under controlled conditions can result in significant improvements in field performance.

Conversely, on a theoretical basis, hardware that has been in the field for any length of time might have had latent defects precipitated to failure purely by the environmental stresses naturally imposed by the field conditions. Under these circumstances, field ESS application would provide only marginal improvement in the field reliability performance.

Application of ESS to all inventory hardware is obviously not practical nor cost-effective. This report provides the basis for selectively applying ESS to field inventoried electronic hardware. Significant potential is offered for improving field reliability and thereby the operational readiness performance of Air Force weapon systems as well as for large reductions in maintenance and support costs. This report analyzes all aspects of the problem, from both test effectiveness and cost viewpoints, and provides guidelines for cost-effective implementation of ESS in the field maintenance environment.

2 - APPROACH

2.1 BACKGROUND

In general, the classical field maintenance removal rate improvement of an electronic equipment due to ESS can be depicted as shown in Fig. 1. The primary objective is to minimize the total removal rate which consists, theoretically, of both latent (workmanship, ESS sensitive defects) and inherent (design life) defects, to at least some improved level which is closely allied to the specified or operational baseline goals.

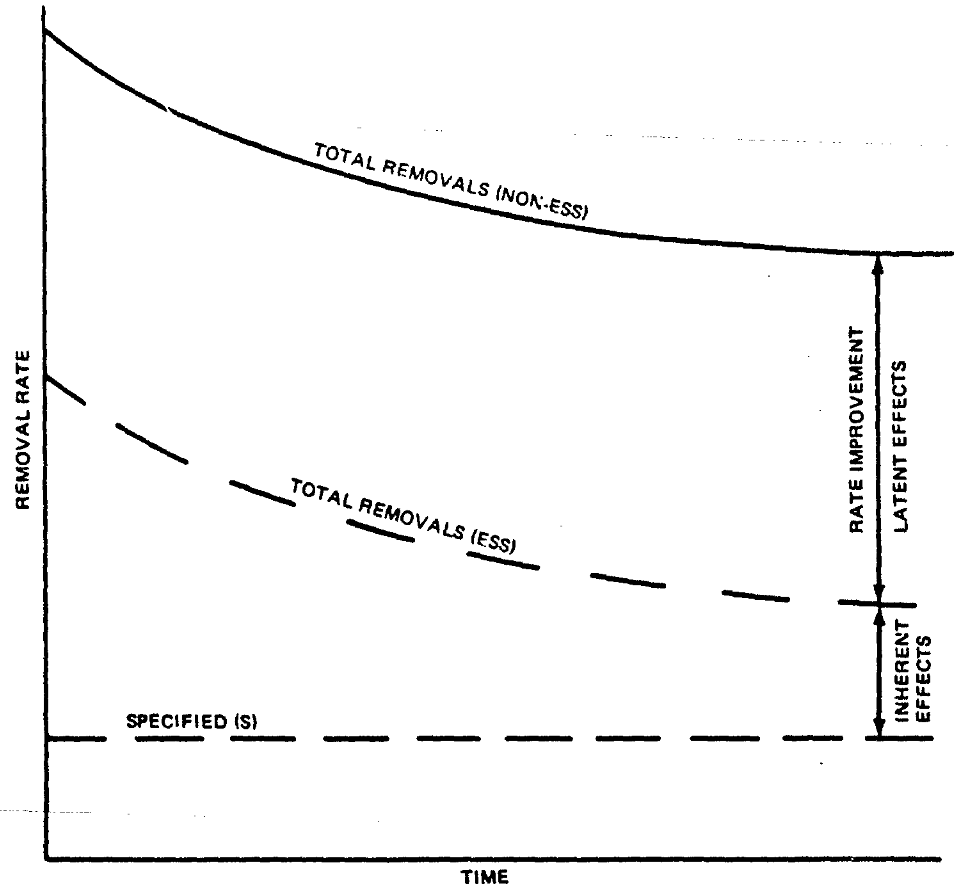

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Figure 1. Typical removal rate improvement effects due to ESS.

The removal rate and its time distribution for a weapon system and its Line Replaceable Units (LRUs) is obtained via the typical field maintenance data and reporting system (Air Force D056, Navy Maintenance and Material Management (3M), Army UMSDC). A properly-designed ESS profile (temperature and vibration) test will effectively reduce the latent defect population, resulting in a gain from a non-ESS removal rate to an ESS rate. The difference or improvement, therefore, should be a function of the latent defect rate reduction, with the resulting rate residue being mostly inherent in nature. It is, however, difficult to demonstrate such a scenario with any clear conviction in a real-world field maintenance environment since, the field data do not always contain:

- Clear definition of failure or effect
- Laboratory failure analysis to classify latency or inherency or other
- Consistent maintenance practices and reporting
- A closed-loop traceability of actions from LRU to piece part without voids in the physical repair process, and hardware identities
- Accurate diagnosis without a multiplicity of no-fault removals for unknown reasons
- Time in service, utilization and operating hours, and power-on time per equipment is at best a function of the weapon systems service time (e.g., aircraft flight hours, system ownership time).

Further, the specified rate which may be defined by handbook predicting techniques (e.g., MIL-HDBK-217), specified contractual goals, or field operational objectives (e.g., R&M 2000 targets), represents purist values and is not quantitatively measurable from field maintenance data for the above reasons. This results in measured comparisons that are clouded by definitions and groundrules. Therefore, the effect of meeting or exceeding a specified value by groundrule, without showing improvement in the field removal rate is almost meaningless from a logistics, readiness, and ultimate life cycle cost point of view.

2.2 APPROACH

Figure 2 outlines the task flow of analyses and assessments performed during this study and described in the subsequent sections of this report. A Field ESS Implementation Guideline is also provided in Appendix C. The basis of the approach is to establish that the differences in removal rates can be realized first by ESS in general, and then by incorporating a planned ESS program in a field maintenance environment at an Air Logistics Command (ALC) facility.

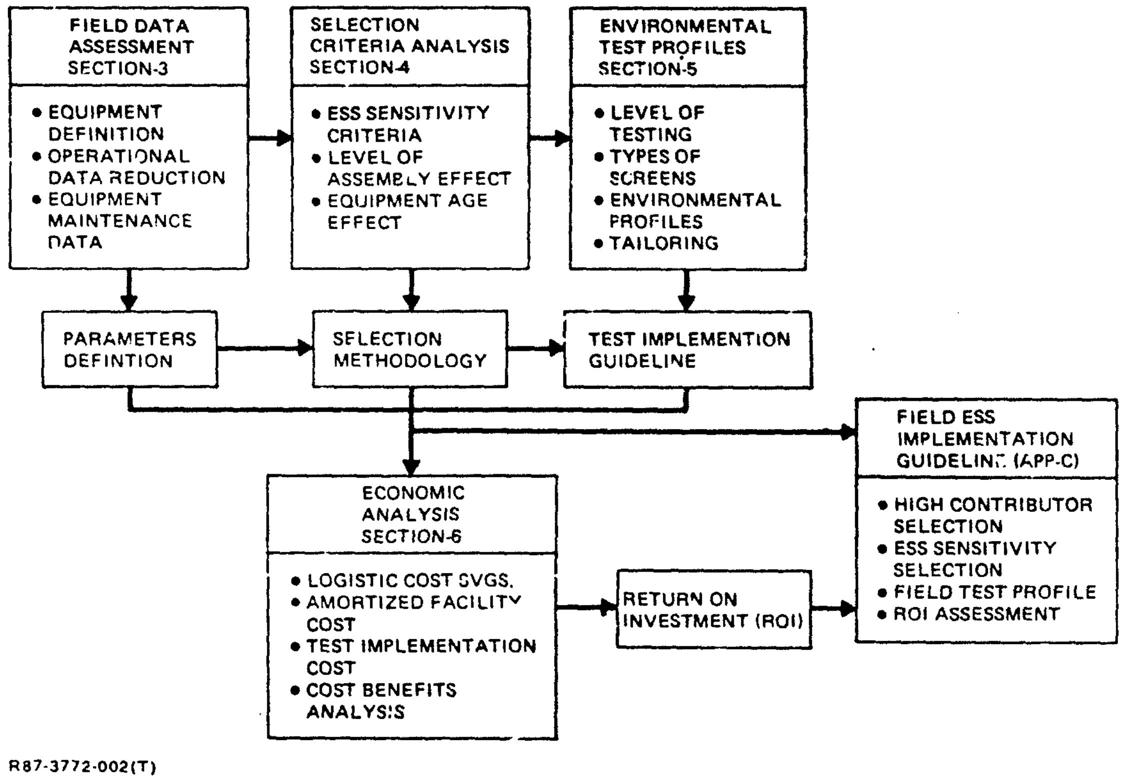


Figure 2. Study operational task flow for ESS selection.

To accomplish this, five case histories of electronic LRUs of varying complexity and design were selected from complex tactical weapon systems. Initially each of the LRUs did not have ESS exposure during their early procurement, either at a vendor or field facility, and each had established long histories of field performance. As a result of product improvement in later years, ESS requirements were introduced for subsequent production lot acceptance, which provided a similar long history of an ESS population that could be directly compared to their non-ESS counterparts. These data provided the means for assessing the effectiveness of ESS under real world conditions of maintenance and use as described by the field maintenance data.

The effects of screening field-aged hardware were assessed using experience data and engineering judgements. Trade-offs between screening implementation costs (facilities, test, repair) and downstream logistic support cost savings over the remaining product life are a critical selection factor. An economic analysis procedure was developed and is presented on a cost benefit Return On Investment (ROI) basis.

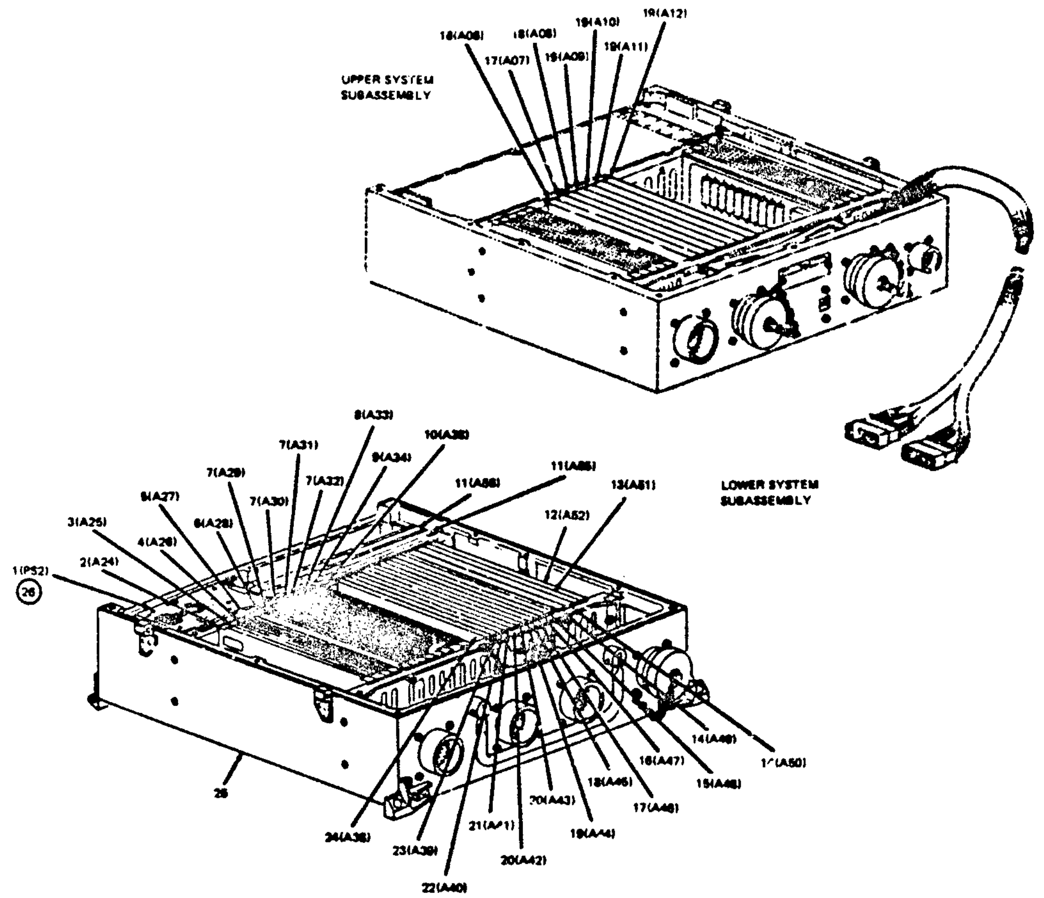
3 - FIELD DATA ASSESSMENT

A field data assessment was performed to study the effectiveness of ESS as a function of actual field operational performance. The assessment was accomplished by selecting five avionic equipment types which had previous field history as non-ESS equipment, and as a result of product improvement, had subsequent production lots subjected to ESS as part of the acceptance test requirements at the manufacturer's facility. All screened units were tested as new, and not previously field-deployed or overhauled. Figure 3 and Table 1 provide the identification, description, physical statistics and features of the LRUs selected. The five equipments were conceived (in design) late in 1960 and introduced to the field in early 1970. The equipment field performance and maintenance history spans six to eleven years for the non-ESS population, and four to five years for the ESS population; thereby providing a sound maintenance data base for making comparisons.

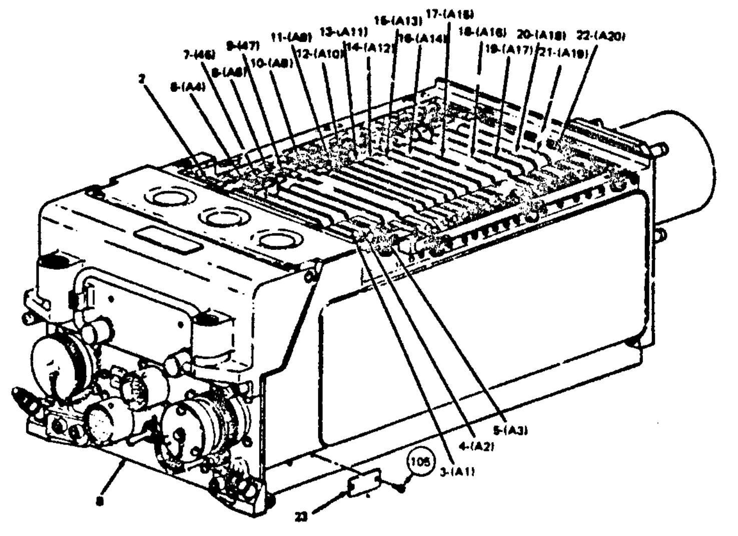
All of the equipments have field maintenance histories, as formally reported in the Navy's 3M reporting system. The data was received in raw magnetic tape format for processing in-house, on a monthly basis. A continuous updating of the historical databases, thus provided as complete a field maintenance history as possible.

3.1 EQUIPMENT SELECTION

The equipments selected for this study are currently in operation use on two aircraft weapons systems, the F-14 and E-2C. As previously noted, the ESS units in all cases were ESS tested at the vendor facility and delivered with the weapon system as new, and not as units pulled from the field and then subjected to ESS. The configuration of the ESS units are very similar to the non-ESS units except for some minor engineering changes/modifications, which is considered a natural process over a ten year period. ESS LRUs were subjected to a formal ESS test which consisted of rapid thermal cycling and random vibration similar to those defined by NAVMAT-P9492 and MIL-STD-2164(EC) (Ref 1 and 2). The specified ESS test characteristics for each equipment are summarized in Table 2 and discussed more thoroughly in Section 5. Data generated for this study spanned an 11 year period (1975-1985) for non-ESS units and five years (1981-1985) for the ESS units.



A- COMPUTER SIGNAL DATA CONVERTER (CSDC)



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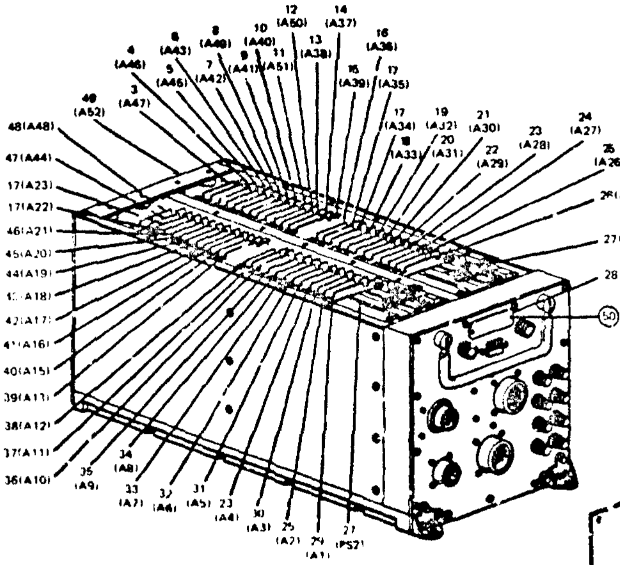
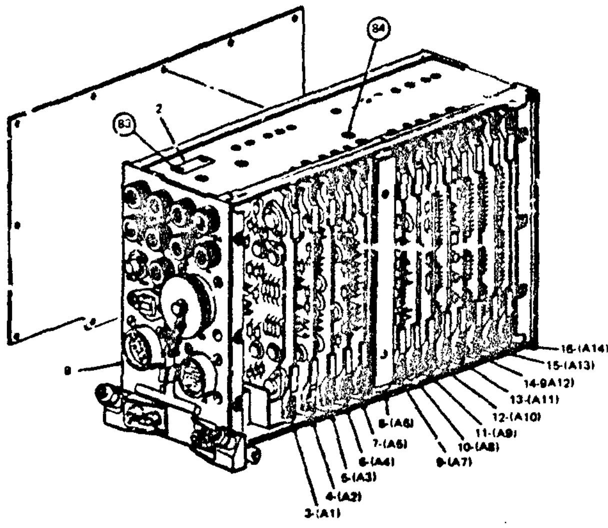
B – CENTRAL AIR DATA COMPUTER (CADC)

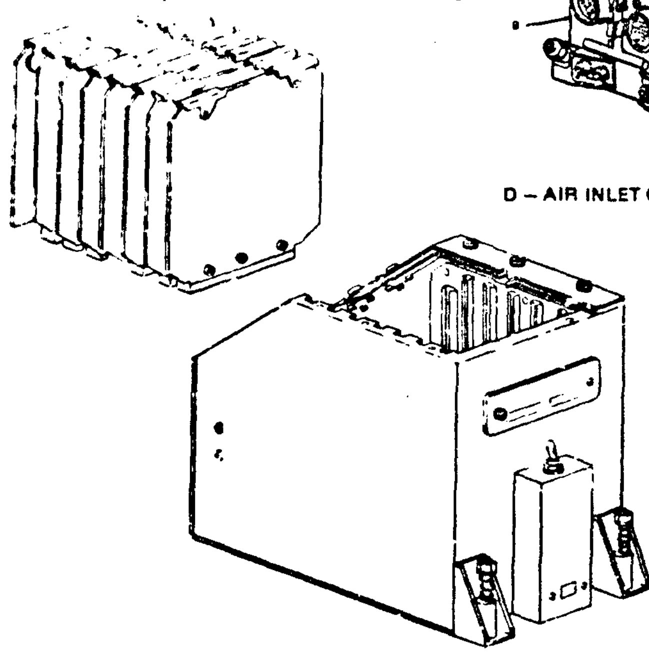
Figure 3. Physical features of selected equipments (sheet 1 of 2).



C – VERTICAL DISPLAY INDICATOR GROUP (VDIG) (CONVERTER)



D – AIR INLET CONTROL SYSTEM (AICS) (PROGRAMMER)



E – SIGNAL COMMAND READOUT & ALARM MODULE (SCRAM)

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Figure 3. Physical features of selected equipments (sheet 2 of 2).

TABLE 1. LRU characteristics.

LRU	BRIEF DESCRIPTION	WEIGHT (LBS)	FORM FACTOR (L x W x H) IN INCHES	SPECIFIED MTCF (HRS)	NO. SRUs	NO. HYBRIDS/ICs (% OF TOTAL PARTS)	OTHER PARTS (% OF TOTAL PARTS)	TOTAL NO. PARTS	QUANTITY PER WEAPON SYSTEM
A (CSDC) COMPUTER SIGNAL DATA CONVERTER	PROVIDES SIGNAL TIMING, FORMATTING, SWITCHING, GENERAL PURPOSE COMPUTATIONAL CAPABILITIES, & INTERFACE COMPATIBILITY BETWEEN ASSOCIATED AVIONICS EQUIPMENT	41.7	13.75 x 12.82 x 6.68	420	49	995 (43)	1325 (57)	2320	1
B (CADC) CENTRAL AIR DATA COMPUTER	PROVIDES AIR DATA FUNCTIONS FOR AIRCRAFT AVIONIC SYSTEMS	33.2	21.1 x 8.7 x 6.7	2070	21	292 (11)	2351 (89)	2643	1
C (VDIG) VISUAL DISPLAY INDICATOR GROUP (PROCESSOR)	RECEIVES INPUTS FROM VARIOUS AIRCRAFT SYSTEMS & PROVIDES ANALOG OUTPUT SUITABLE FOR GENERATING ANALOG DISPLAY INDICATOR SYMBOL DISPLAYS	56.1	25.0 x 10.4 x 9.4	202	51	2704 (50)	2711 (50)	5415	1
D (AICS) AIR INLET CONTROL SYSTEM (PROGRAMMER)	PROVIDES THE CONTROL & FAILURE MONITORING FUNCTIONS OF AIRCRAFT AIR INLET CONTROL SYSTEM	14.0	16.0 x 4.0 x 7.0	3000	15	169 (12)	1257 (88)	1426	2
E (SCRAM) SIGNAL COMMAND READ OUT & ALARM MODULE	PROVIDES INTERFACE BETWEEN COMPUTER PROGRAMMER (CP) & AVIONIC SUBSYSTEMS BEING MONITORED	8.0	10.0 x 5 x 6.7	5000	8	139 (51)	136 (49)	275	6

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TABLE 2. ESS test characteristics.

LRU	THERMAL CYCLING T/C	VIBRATION BEFORE & AFTER T/C	NO. OF CYCLES		CYCLE DURATION (HRS)
			BURN-IN	FAILURE FREE	
A	-54° TO +71°C @ 5°C/MIN.	• RANDOM -4.9 GRMS FOR 15 MIN. • SIN – 1.5 G FOR 10 MIN. OF EACH HR ON TIME (35 HRS)	18	34	5.5
B	-54°C TO +71°C @ 5°C/MIN.	• SIN – 1.5 G FOR 10 MIN. OF EACH HR ON TIME (17 HRS)	20	20	4.0
C*	-54°C TO 71°C @ 5°C/MIN	• RANDOM – 5.2 GRMS FOR 10 MINUTES • SIN – 1.5 G FOR 10 MIN. OF EACH HR ON TIME (10 HRS)	10	20	4.0
D	-54°C TO +71°C @ 5°C/MIN.	• SIN – 1.5 G FOR 10 MIN. OF EACH HR ON TIME (14 HRS)	5	32	3.75
E	-40°C TO +55°C @ 5°C/MIN	• RANDOM – 6.06 GRMS FOR 15 MIN.	35	25	1.75

*DENOTES THAT THE RANDOM VIBRATION PORTION OF THE ESS TEST IS APPLIED TO 1 OUT OF EVERY 9 LRUs AS A MINIMUM

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Table 3 presents all five case histories with all the associated statistics, drawn m the 3M database. As note , a significant number of units reporting (different ialized LRUs) are identified in each category, providing a sound statistical base.

TABLE 3. Case histories — removal reporting statistics

	NON-ESS							ESS						
...NT	TOTAL NO. A/C REPORTING	TOTAL NO. FLIGHT HRS	YRS OPERATION	TOTAL NO UNITS REPORTING (SER NO. LRUs)	TOTAL NO REMOVALS FOR CAUSE	AVG. NO. REMOVALS/ UNIT	MFHBR	TOTAL NO. A/C REPORTING	TOTAL NO. FLIGHT HRS	YRS OPERATION	TOTAL NO. UNITS REPORTING (SER NO. LRUs)	TOTAL NO. REMOVALS FOR CAUSE	AVG. NO. REMOVALS/ UNIT	MFHBR
	222	370,437	11	1106	11695	10.5	32	114	120,140	4	587	1718	2.9	70
	222	370,437	11	970	5631	5.8	66	114	120,140	4	453	949	2.1	127
	222	370,437	11	849	4445	5.2	83	114	120,140	4	432	805	1.9	149
	222	370,437	11	1029	4038	3.9	92	114	120,140	4	285	433	1.5	278
	47	126,667	6	377	1330	3.5	570*	22	53,157	5	158	287	1.8	1110*

/G 6 UNITS PER A/C

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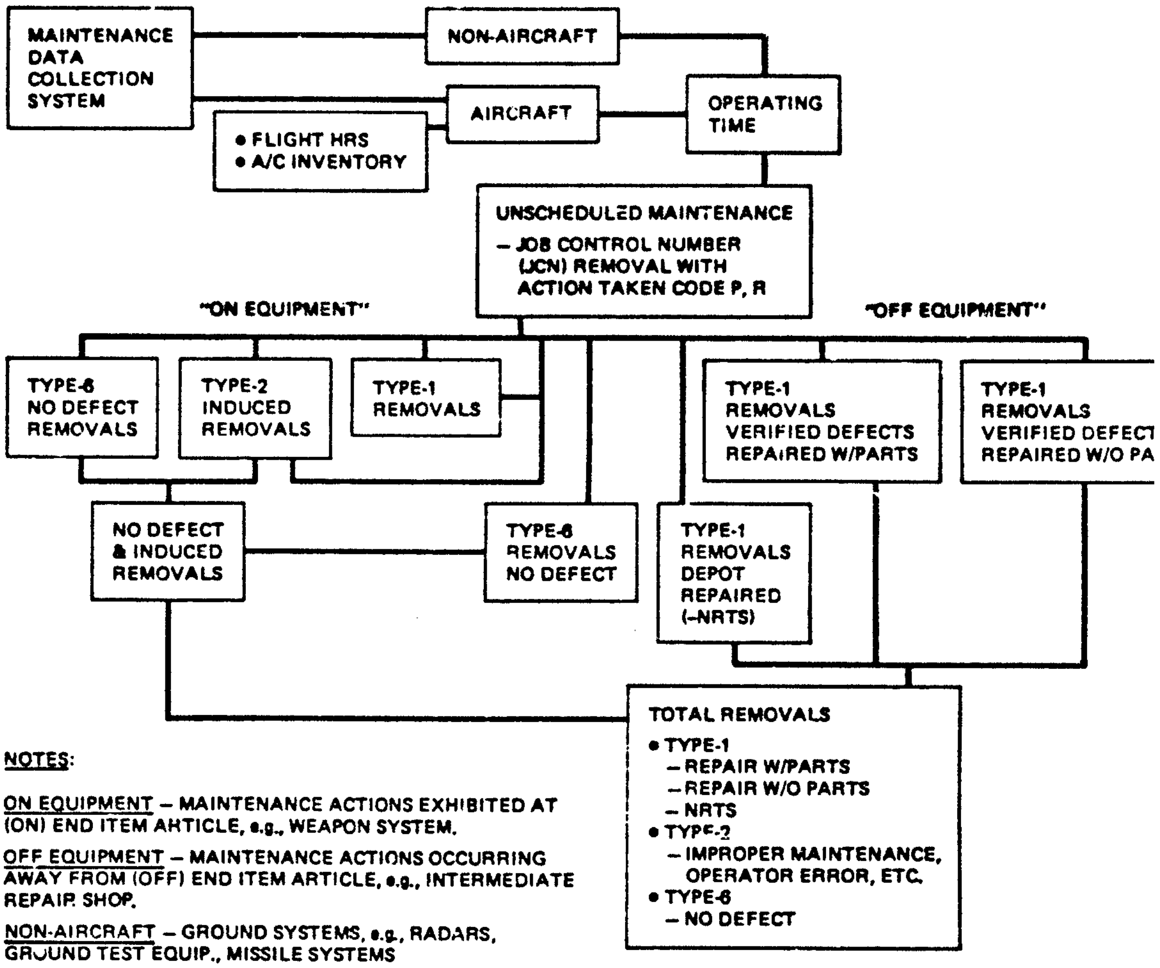
2 FIELD DATA REDUCTION

The intent of Field Data Reduction is to glean from the maintenance data system ose indicators and parameters which can be used for tracking field maintenance rformance, and to assist in the selection of candidate equipments or groups of uipment that could be sensitive to corrective ESS in the field. Figure 4 illustrates e process used to categorize the data as derived from the maintenance and repair rocess.

In reducing Navy 3M data, strict compliance with Air Force maintenance (D056) tion definitions and how malfunction coding were maintained to ensure at action taken traceability provided for final disposition of the maintenance action.

All of the Job Control Numbers (JCN) generated are associated with unscheduled type maintenance (TM code = B) and action taken (AT) codes P (removed) nd R (remove and replace) as per AFR-300-4 (Vol 3). Selection of these parameters permits us to focus on the removals for cause maintenance actions and eliminates e remove for access, cannibalization, and unrelated actions not bearing on the reair disposition of the hardware. This refinement of the field data presents a lean-cut accountability for the pertinent maintenance actions, which is essential for he ESS Effectiveness Analysis discussed in the subsequent sections of this report.

The Air Force D056 Maintenance Data Collection System contains three maintenance categories as defined by AFR 800-18 and identified in Fig. 4:



NOTES:

ON EQUIPMENT – MAINTENANCE ACTIONS EXHIBITED AT (ON) END ITEM ARTICLE, e.g., WEAPON SYSTEM.

OFF EQUIPMENT – MAINTENANCE ACTIONS OCCURRING AWAY FROM (OFF) END ITEM ARTICLE, e.g., INTERMEDIATE REPAIR SHOP.

NON-AIRCRAFT – GROUND SYSTEMS, e.g., RADARS, GROUND TEST EQUIP., MISSILE SYSTEMS

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Figure 4. Field data reduction.

(1) Type 1 Inherent Malfunctions - activity resulting from malfunctions that occur from internal design and manufacturing characteristics. This c egory consists of both repair with definable part or component assemb and repair without parts, e.g., inadequate/excessive solder, loose pai etc. Repair with parts consist of those removal devices e.g., LRUs ('14' card at '0' level) requiring the removal/replacement of SRUs ('14' card 'I' level) and/or direct removal of piece parts ('P' card)

(2) Type 2 Induced Malfunctions - activity resulting from malfunctions that occur from external sources, e.g., improper maintenance, operator er foreign object damage, failures due to malfunction of associated equ ment, etc

(3) Type 6 No Defects - activity resulting from malfunctions which could not be Confirmed nor Duplicated, (CND), e.g., removals which subsequently bench check satisfactory, and is reported on How Malfunction (HM) code 799 (no defect) only.

3.3 EQUIPMENT OPERATIONAL PERFORMANCE

In tracking the equipment's field maintenance performance, strict attention was paid to LRU serial number identification and traceability. Without the traceability and reporting of LRU serial numbers, the task of segregating the non-ESS from the ESS population would have been almost impossible. SRU and lower level assemblies were in no way traceable or accountable. The basis of operating time in all cases was flight hours as accumulated by aircraft block numbers known to contain non-ESS or ESS equipment. Specific blocks of hardware serial numbers were assigned to specific blocks of aircraft. By continuously cross-matching the blocks on a monthly basis, all removals and all flight hours were accounted for in each non-ESS and ESS category. Where any mixing or mismatching appeared, the data was eliminated completely.

Figure 5 provides the annual historical trends of each case history equipment for both the non-ESS and ESS populations. The bar charts are expressed in terms of removals per 1000 flight hours, and provide the distribution of Type 1, Type 2, and Type 6 actions for each population. The only common ground noted on this basis is the consistent reduction in the removal rate pattern of the ESS populations.

Figure 6 provides the summary of the statistics developed for each of the populations and the resulting rate improvements derived from the difference between the non-ESS and ESS groups. It is apparent from these comparisons that a significant improvement has been manifested across the board for all equipments, with the overall removal reduction ranging between 48% and 67% (at least a 2:1 ratio). With the absence of physical failure analysis reporting data, which does not exist in field maintenance data, it is extremely difficult to attempt to quantify which defect groups might be classified as latent (workmanship) or inherent (design). Intuitively, Type 1 repair without parts, Type 6, and Type 2 conditions would more than likely contain the bulk of latent related defects; and the Type 1 repair with parts would contain mainly the inherent or design sensitive defects. It should be noted that Type 2 defects are almost non-existent in any of the maintenance reporting systems.

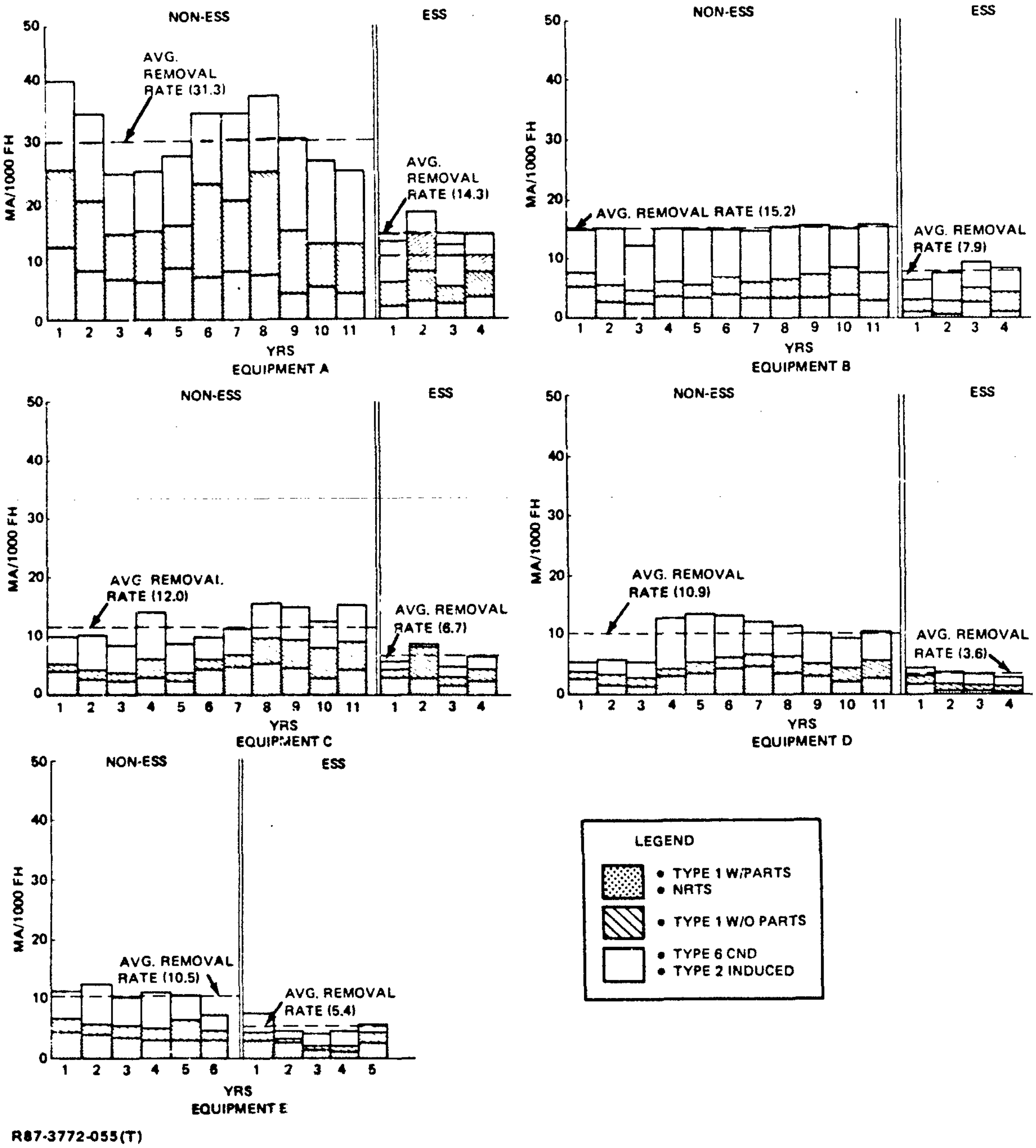

Figure 5. Annual historical trends 1975 – 1985 (Navy 3M database).

EQUIP.	TOTAL REMOVALS AVERAGE NON-ESS RATE	AVG ESS RATE	% RATE RED.	TYPE-1 • REPAIR W/PARTS • NRTS NON-ESS RATE	ESS RATE	% RATE RED.	TYPE-1 • REPAIR W/O PARTS NON-ESS RATE	ESS RATE	% RATE RED.	TYPE-2&6 • 799 CND • INDUCED NON-ESS RATE	ESS RATE	% RATE RED.
A	31.3	14.3	54	7.3	2.8	62	11.3	4.2	63	12.7	7.3	43
B	15.2	7.9	48	3.8	1.7	55	2.8	2.2	21	3.8	2.0	47
C	12.0	6.7	44	3.8	2.5	34	2.8	1.7	39	2.1	0.9	57
D	10.9	3.6	67	3.0	1.2	60	1.9	0.7	63	2.9	0.8	72
E	10.5	5.4	49	3.6	2.2	39	2.2	0.9	59	2.9	1.4	52

NOTES:

RATES = MA/1000 FH

NON-ESS RATE = 11 YR AVG

ESS RATE = 4 YR AVG

RED. = REDUCTION IN RATE = $\frac{(\text{NON ESS} - \text{ESS})}{\text{NON ESS}}$

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Figure 6. ESS effectiveness assessment.

In assessing the effect of ESS on each equipment during growth evolution, Tables 4 and 5 were developed to contrast the growth of the non-ESS equipment over the 11 year span. A comparison of the rate distributions for the first two years of field operation was made with the latest two years to determine the effect (if any) of engineering changes and system improvements on the latest configured non-ESS groups. The comparisons are made for the Type 1 repairs with parts (to reflect potential inherent changes) and the combined Type 1 repairs without parts, plus Type 6 and Type 2 actions (to reflect potential latent rate changes). The results as shown in Table 4 indicate that the most significant improvement of the non-ESS population over the years is contributed by the inherent type rate (Type 1 repair with parts). This would be expected as a result of the design and reliability improvement changes incurred over the years. The latent defect type group, on the other hand, is for the most part significantly deteriorating (negative improvement %), indicating that any improvement activities did not affect workmanship and related maintenance induced type actions.

Table 5 contrasts the last two years of performance of the non-ESS population with that of the ESS population to provide a transitional growth effect in going from the latest field improved hardware to the newly delivered ESS hardware. In these comparisons, although the Type 1 repairs with parts (inherent related category) rates are improved across the board, the rate reduction is not as great as the

TABLE 4. Non-ESS growth effects as a function of type action distributions.

	TOTAL REMOVALS			TYPE-I • REPAIRS W/PARTS • NRTS			TYPE-I PLUS (TYPE 6&2) • REPAIR W/O PARTS • 799 CND • INDUCED		
EQUIP	INITIAL RATE	LATEST RATE	% RED	INITIAL RATE	LATEST RATE	% RED	INITIAL RATE	LATEST RATE	% RED
A	31.3	20.4	35	10.7	5.0	53	20.6	15.4	25
B	9.8	11.5	(-)17	4.1	3.6	12	5.7	7.9	(-)39
C	7.5	10.6	(-)41	3.4	3.7	0	4.1	6.9	(-)68
D	6.1	7.6	(-)25	2.2	2.5	0	3.9	5.1	(-)32
E	10.1	7.3	28	4.4	2.9	34	5.7	4.4	23

NOTES

RED = REDUCTION IN RATE = $\frac{\text{(INITIAL − LATEST)}}{\text{INITIAL}}$

RATES = MA/1000 FH
INITIAL = INITIAL TWO (2) YEARS OF SERVICE
LATEST = LATEST TWO (2) YEARS OF SERVICE
(-) = DEGRADATION (NEG. GROWTH)

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TABLE 5. Transitional growth & effect – Non-ESS vs ESS groups.

	TOTAL REMOVALS			TYPE-I • REPAIR W/PARTS • NRTS			TYPE-I PLUS (TYPE 6&2) • REPAIR W/O PARTS • 799 CND • INDUCED		
EQUIP	NON ESS RATE	ESS RATE	% RED	NON ESS RATE	ESS RATE	% RED	NON ESS RATE	ESS RATE	% RED
A	20.4	10.6	48	5.0	2.8	44	15.4	7.8	49
B	11.5	5.9	49	3.6	1.7	53	7.9	4.2	47
C	10.6	5.2	51	3.7	2.5	32	6.9	2.7	61
D	7.6	2.8	63	2.5	1.2	52	5.1	1.6	69
E	7.3	4.5	38	2.9	2.2	24	4.4	2.3	48

NOTES

RED = REDUCTION IN RATE = $\frac{\text{(NON ESS − ESS)}}{\text{NON-ESS}}$

RATES = MA/1000 FH
NON ESS = LATEST TWO (2) YEARS OF SERVICE
ESS = LATEST TWO (2) YEARS OF SERVICE

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change in the Type 1 repair without parts plus Type 6 and Type 2 actions (latent related category) which provides the predominant weight on the overall removal rate reduction. The sensitivity of this effect is predominantly ESS oriented.

However, since inherent and latent characteristics are extremely difficult to quantify without supporting failure analysis data, the most significant attributes that can be derived as a result of effective screening are:

- Reduction in overall removal rate
- Stabilization of frequency and dispersion patterns.

Figure 7 shows the dispersion of each LRU population removal rate on a monthly basis for a five year period (1981-1985) in order to assess the removal frequency patterns of the ESS hardware with the comparable level non-ESS growth hardware. The bell-shaped frequency curves are the frequency distribution of the monthly averages, which were graphed to determine if the frequency pattern of the non-ESS vs ESS population of the LRU were in any way related, since they are essentially of the same hardware functionally. Each population (ESS vs non-ESS) had 60 reporting points (five years x 12 months/year). The dispersion, in a qualitative sense, is expressed by the broadness of the range values about the mean or average rate for the population. Equipment A, as an example, had monthly rates for the non-ESS population that ranged between 10 and 50 actions per 1000 flight hours, while the ESS group ranged between five and 25. The percent frequency on the Y axis is the percentage of time the value appears over the five year span. The more consistent the removal rate, the higher the frequency should be about the average value. With respect to Equipment A, non-ESS, the approximate frequency about the average (31.3) is only 25%, while that of the ESS population (14.3) is near 60%.

The cumulative frequency curves represent the percentage of values that fall below a certain value. For Equipment A, approximately 50% of the monthly values were 30 or less for the non-ESS population, while the ESS population had 100% of its values less than 30. In contrast, the ESS population had 90% of its values at 20 or less, while the non-ESS population had only 20% at 20 or less.

The frequency distributions in every case history comparison, ESS vs non-ESS, barely overlap and in about every case the average of the non-ESS population does not appear at all in the ESS distribution. No further statistical manipulation is

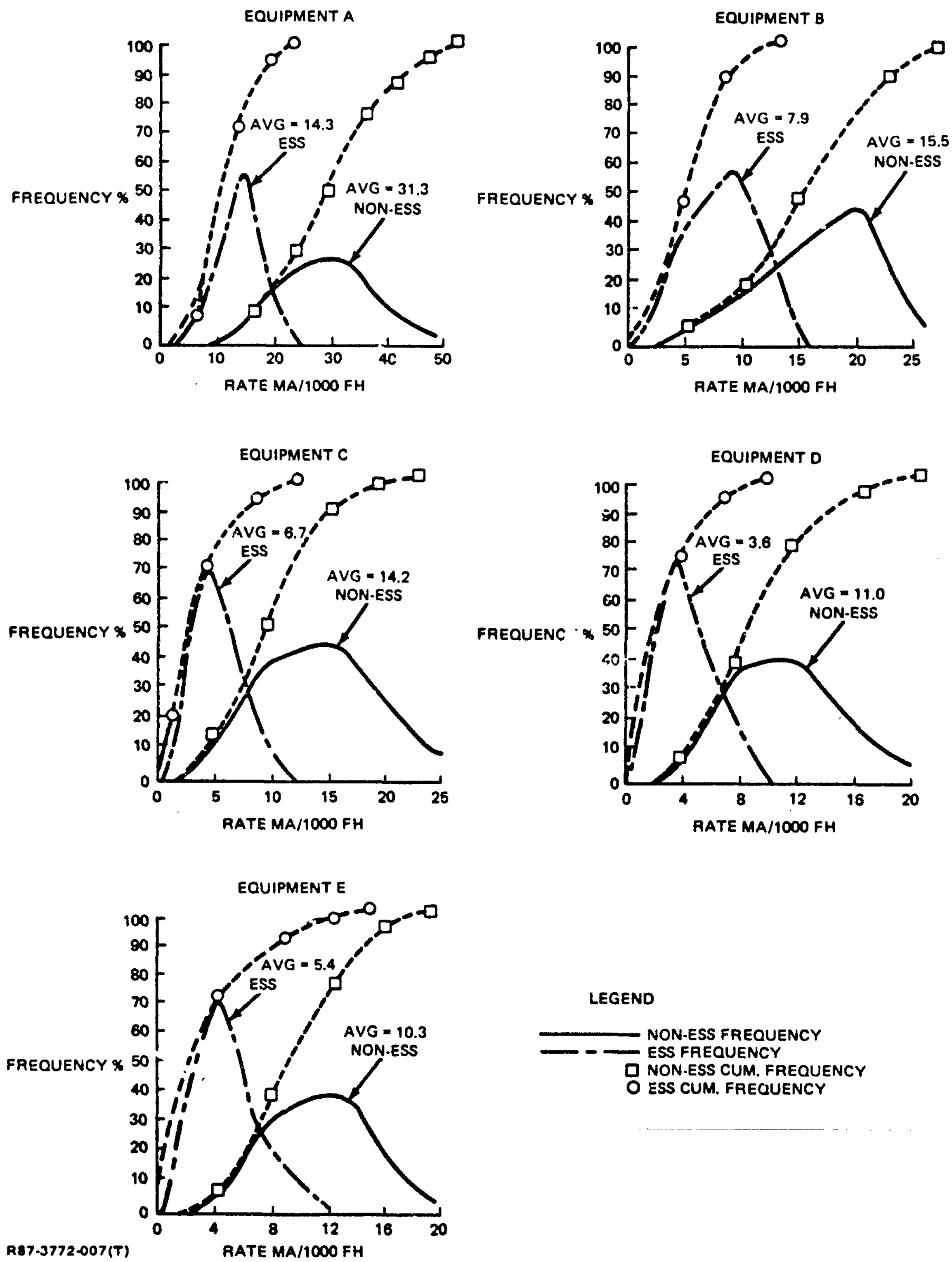

Figure 7. Frequency distribution of removal rates ESS vs non-ESS equipment groups.

needed to conclude that these populations of like hardware are not related on this basis and that the ESS populations are significantly more stable about the average values.

With the common ground of the ESS populations being that they were all screened as new, the results tend to indicate that, as a result of ESS testing on at least new production hardware, the overall removal rates and dispersions over a significant period of time have been reduced and stabilized (less dispersion about the average). The characteristics of these dispersions in terms of make-up as a function of the specific distribution of removals per unit, and any skewness effects derived there from, are discussed in Section 4.

4 - SELECTION CRITERIA ANALYSIS

In the field implementation of ESS, three major areas must be addressed before equipment selection decisions can proceed. These are:

- ESS Sensitivity Potential - equipment maintenance rate history sensitivity to ESS and the criteria basis to support the decisions
- Level of Assembly Testing - equipment population and level of assembly sensitivity to defect distribution and repairability factors
- Equipment Age - equipment age in terms of years of service, and the potential effect of ESS in both the near term (i.e., can the equipment survive?) and the long term (i.e., is there a payoff in extended reliability and service?).

In the management of these processes, initial decisions as to the selection of equipment to test, at least on a noneconomic basis, is possible.

4.1 ESS SENSITIVITY POTENTIAL

It should be understood that quality of testing, not quantity, is the objective. Further, the objective is not to attempt elimination of every conceivable defect, since this is physically and economically impossible. Rather, the objective is to dilute the defective population as optimally and as quickly as possible within cost constraints without affecting the standing readiness of operational weapon systems and field activities. Thus the approach for equipment selection is to establish:

- High removals for cause
- Highest potential for reliability improvement
- High bad actor sensitivity.

4.1.1 Removals For Cause

A review of the removal history of avionics of various aircraft weapon systems indicates that the removals are concentrated in relatively few equipments. As shown in Fig. 8, approximately 10% of the avionic equipment was installed; as identified by Work Unit Codes (WUCs) 5 (Instrumental Navigation), 6 (Communications/Naviga-

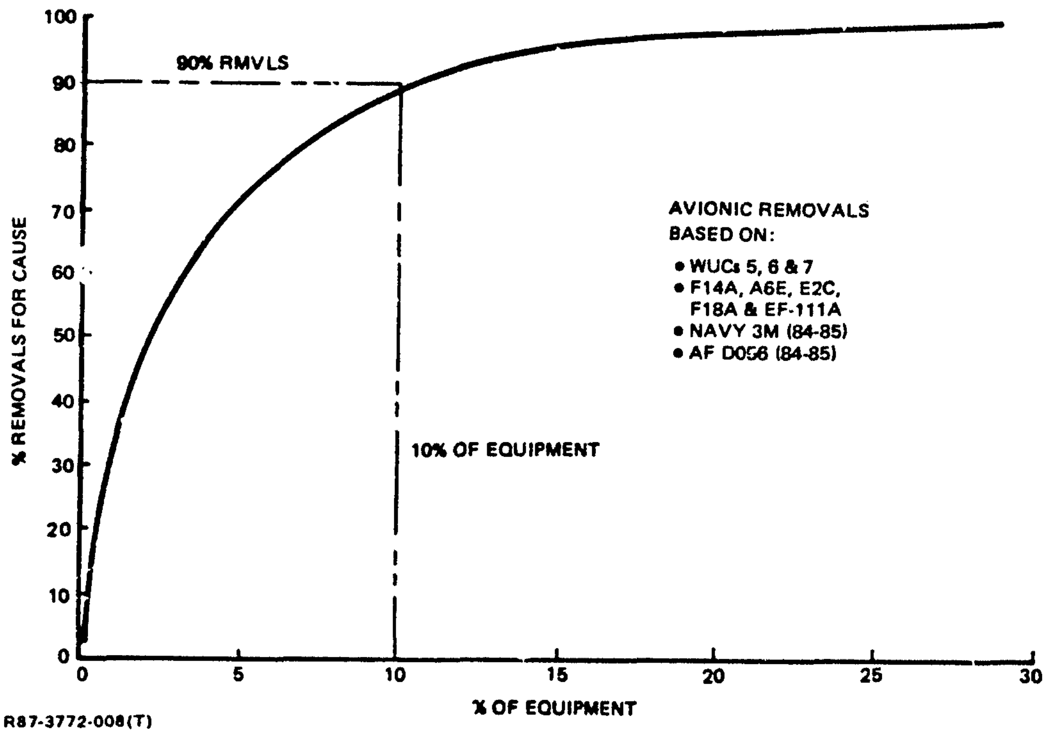

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Figure 8. Composite distribution of % of avionic removals vs % of electronic/avionic equipment contribution.

tion), and 7 (Weapon Systems); in the F-14A, A-6E, E-2C, F-18A and EF-111A aircraft accounted for 90% of the LRU removal actions on those aircraft. This suggests that candidate equipment for ESS testing come from this population of high removal units since they have the highest payoff potential.

Taking this one step further, ranking the avionic equipment and LRUs by high removals for each of the aircraft weapon systems provides the average cumulative rank distributions as shown in Fig. 9. The equipment rank (3 digit WUC) provides between 80 to 90% of the removals in the electrical avionic categories (WUC, 5, 6 and 7) within the top ten ranked. A top-down ranking of the LRUs (4 digit WUC) provides between 60 to 70% within the top 15 to 25 ranked LRUs. Selection judgement should be used in qualifying the high contributor LRUs. Factors to be considered include:

- Hardware serialization
- Repairable status (it is desirable to select repairables only, not expendables or disposables)
- Clear equipment identification and/or part number (e.g., AN/ALQ-XXX)
- No miscellaneous (catchall), or Not Otherwise Coded (NOC) categories.

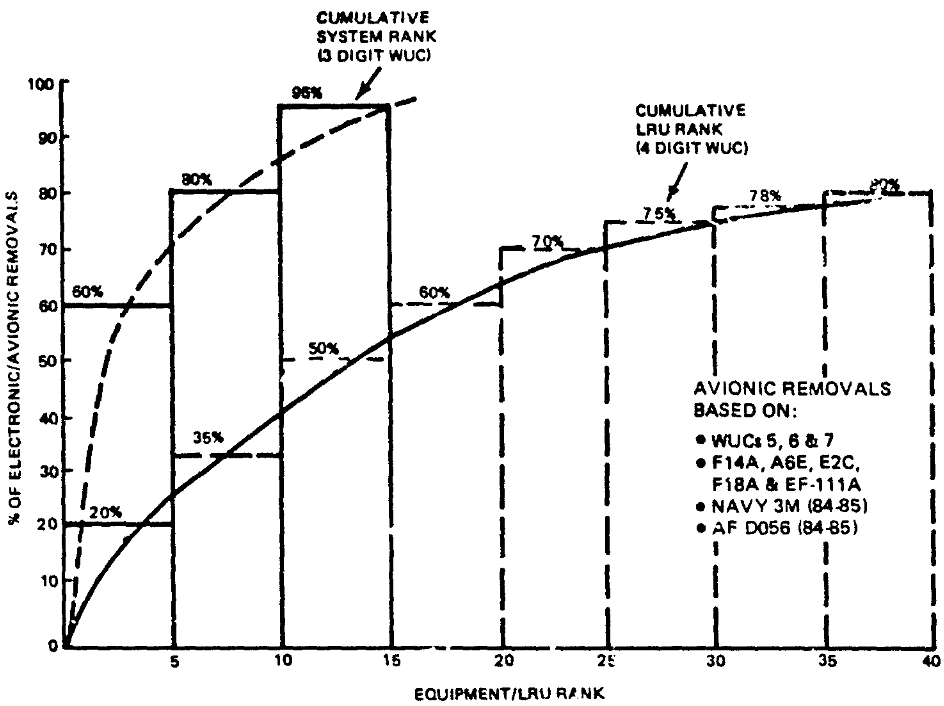

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Figure 9. Average top down rank distribution of electronic/avionic system/LRUs (WUC categories 5, 6, & 7).

The same conclusions apply to ground electronics since similar patterns of concentration have been observed for electronic type hardware.

4.1.2 Potential For Reliability Improvement

The basis for high potential reliability improvement is the relationship between the measured Mean Time Between Removals (MTBR) and the specified Mean Time Between Failure (MTBF) and expressed as the discrimination ratio (MTBF/MTBR). The specified MTBF in this sense is the design or operational reliability measure, as defined by handbook predicting techniques (e.g., MIL-HDBK-217), specified contractual goals (e.g., warranties), field operational objectives (e.g., R&M 2000 targets), or logistics planning goals (e.g., wartime loading levels). This relationship between specified and actuals is typically illustrated in Fig. 10 and shows that Discrimination Ratios (DR) of greater than one would provide the best potential for implied reliability improvement (in the sense frequency reduction). Therefore:

$\frac{MTBF}{MTBR} > 1$; has the highest reliability impact potential and

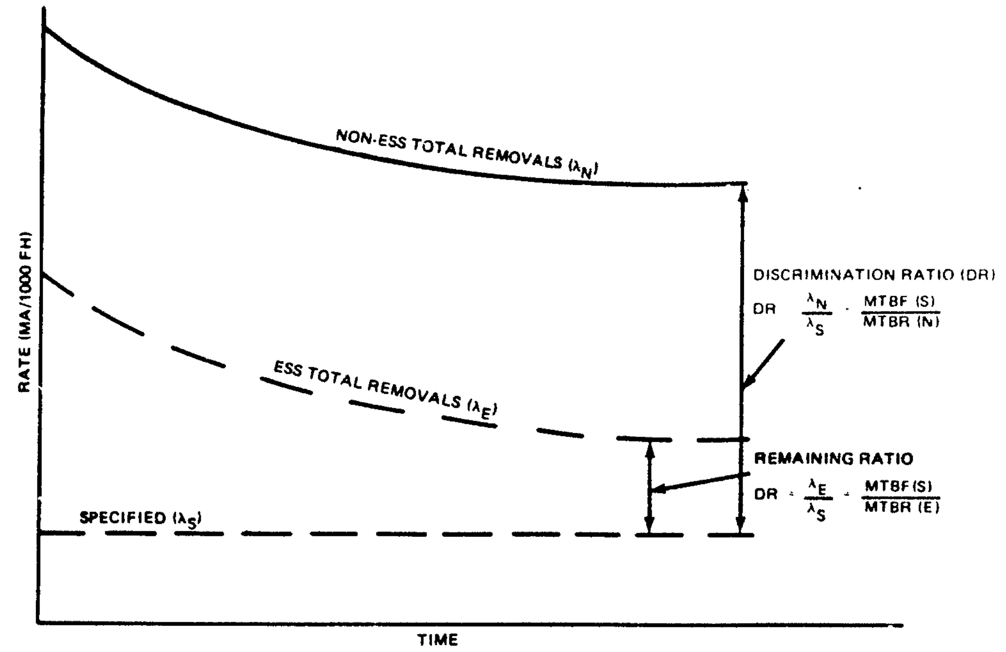

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Figure 10. Difference effects between measured removals & specified reliability.

$\frac{MTBF}{MTBR} \leq 1$; has the least reliability impact potential

It would seem that the larger the ratio (greater than one), the more effect ESS will have on the item's potential reliability improvement. Table 6 provides the DBRs for the case history LRUs for both ESS and non-ESS populations. In each case the initial ratio of specified to non-ESS removals is greater than one, in the range of 2.4 to 32.6. Overall, the average ratio improvement is 2:1, irrespective of the initial ratio magnitude greater than one. It is obvious from the results that no clear correlation can be drawn with respect to specified or predicted levels, and the actual rates. This implies that the defects removed are independent of the design or predicted failure rate; only the quality attributes are affected by ESS.

TABLE 6. Impact of ESS on reliability improvement potential.

EQUIPMENT	NO. UNITS PER SYSTEM	SPECIFIED MTBF	NON-ESS MTBR	ESS MTBR	DISCRIMINATION RATIO		% RATIO REDUCTION
					NON-ESS	ESS	
A	1	420	32	70	13.1	6.0	54
B	1	2070	66	127	31.4	16.3	48
C	1	202	83	149	2.4	1.4	42
D	1	3000	92	278	32.6	10.8	67
E	6	5000	570	1110	8.8	4.5	49

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To illustrate this effect, consider two equipments (x) and (y). Equipment (x) has a specified MTBF of 100 hours and (y) has an MTBF of 1000 hours. By virtue of the manufacturer, ten workmanship defects are inserted into each equipment. If it is assumed that during the normal course of operation of the equipments (x) and (y) the defects are precipitated within 1000 hours of operation, the removal distribution and resulting discrimination ratio (DR) for each equipment would be as follows:

Equip	Hrs (T)	Specified MTBF	Rmvls Due to Failure $\frac{MTBF}{T}$	Rmvls Due to Workmanship Defects
x	1000	100	10	10
y	1000	1000	1	10

Equip	Total Rmvls (R)	Meas. MTBR $\frac{T}{R}$	DR $\frac{MTBF}{MTBR}$
x	20	50	2:1
y	11	91	11:1

Each equipment shows the same thing (there are 10 workmanship defects), but equipment x appears less affected on the surface than y since it is expected to have a low MTBF, and equipment (y) is probably giving the best indication that something is wrong. If we increase the operating time to 10,000 hours (assuming that the defects will be precipitated within the 10,000 hours), the removal distribution for each equipment would now look as follows:

Equip	Hrs (T)	Specified MTBF	Rmvls Due to Failure $\frac{MTBF}{T}$	Rmvls Due to Workmanship Defects
x	10,000	100	100	10
y	10,000	1000	10	10

Equip	Total Rmvls (R)	Meas. MTBR $\frac{T}{R}$	DR $\frac{MTBF}{MTBR}$
x	110	90	1.1:1
y	20	500	2:1

Figure 11 illustrates this operating time effect. Within 1000 hours, both (x) and (y) could be high contributor candidates. After 10,000 hours, (x) would be the only contributor of concern, yet both would have contributed the same to the total aggregate workmanship population of defects. The defect rates per unit are the same, the failure rates are different. Ground electronic equipment and systems which are low production density will be highly sensitive to this effect.

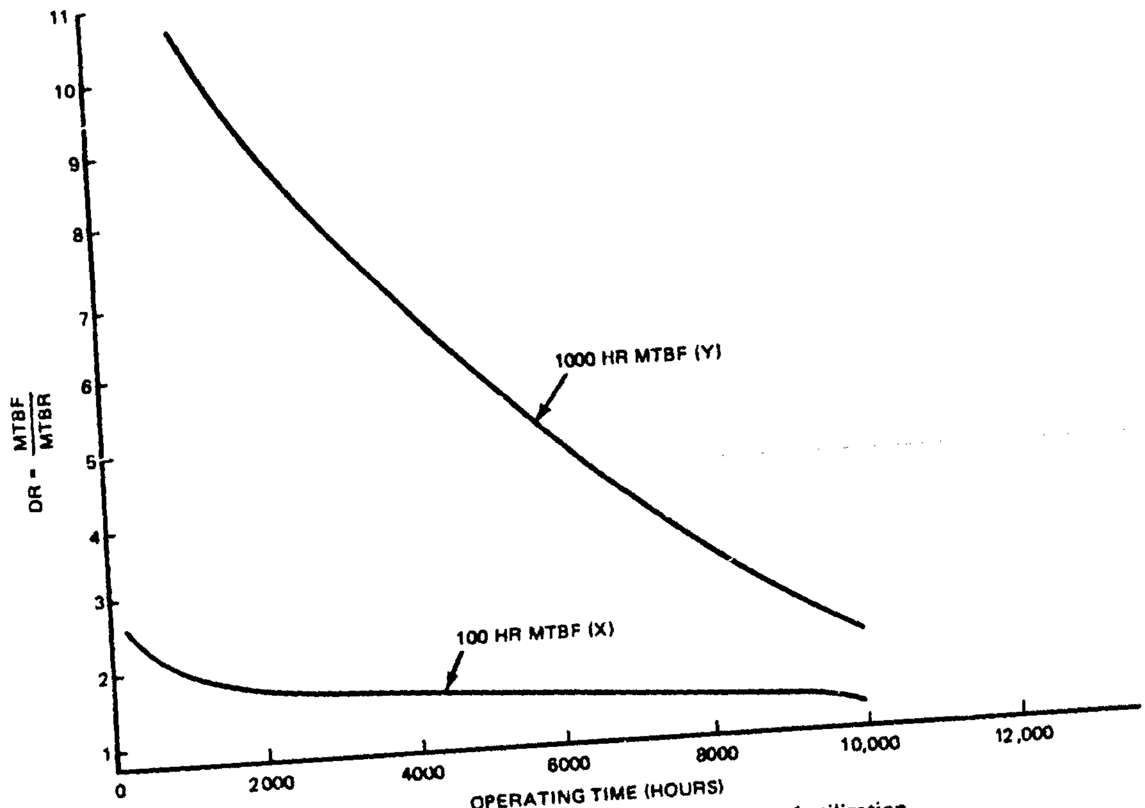

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Figure 11. Reliability/discrimination ratio effect as function of utilization for illustration equipment X & Y having the same defective rate.

In the review of Table 6, the fact that equipment (C) has the lowest discrimination ratio does not make it any lesser a candidate for screening than those having discrimination ratios greater than 30, e.g., equipments (B) and (D). It is obvious that in all cases, except for equipment (E) they are high frequency contributors irrespective of their specified or predicted MTBF. In the case of equipment (E), although the per unit frequency is low, the aggregate (there are six of these per system) is high and in effect poses the same type of problem as the others when truly assessing the reliability and readiness effect.

As noted in the ESS discrimination ratio column, the DRs in each case still exceed one. Thus, either the retention of residual latent defects is not completely removed by the screen, which is realistically possible (since the efficiency of screens is not 100%), or the true MTBF of the unit does not meet or exceed the specified MTBF which, without further discussion of failure definition, is probable for significantly higher DRs. In either case, you would not continue or re-test units previously tested.

It is possible to have DRs less than one (where the measured MTBR meets or exceeds specified MTBF) as well as workmanship defects, since defects do not discriminate as a function of the unit's reliability. However, it is not likely that these defects will affect the intended design performance of the unit or system, and they would not be considered candidates.

Therefore the selection attributes for field reliability improvement potential via ESS should consider:

- The units contribution to the total weapon system removal rate; the higher the contribution, the more the potential
- The number and configuration of units required per system to affect the aggregate rate
- The actual rate falls below expected or specified irrespective of degree.

4.1.3 Bad Actors Sensitivity

On the basis of average rates, as described in the previous section, each unit in the population would have to be tested to achieve an aggregate effect. However, this is not the case in a non-homogeneous process where not all units are defective in a quality sense. Further, each equipment in the field population has an established history or field process average, which provides the basis for selection. Table 7 and Figure 12 show how removals are distributed by serial number. Again concentration effect is evident since 75% of the population removals are caused by 50% of the serial numbers. In addition, the worst 20% of the serial numbers contribute up to 45% of the equipment removals. This would be typical of a quality process effect showing up the potential bad actor boxes by their higher than average removal frequency thus affecting the population average. This would imply that selecting bad actors (or loser boxes) by serial number from a population of serialized LRUs, provides a means for improving the total aggregate removal rate by screening only a select number of units.

TABLE 7. Cumulative % rank serial number removal distribution for non-ESS equipment populations.

EQUIPMENT		CUMULATIVE % RANK 10%	20%	30%	40%	50%	REMAINING > 50%	TOTALS	SERVICE YRS
A	N	111	222	333	444	555	551	1106	11
	RMVLS	2690	5029	6783	8186	9356	2339	11695	
	% RMVLS	23	43	58	70	80	20		
B	N	97	194	291	388	485	485	970	11
	RMVLS	1689	2703	3543	4167	4697	1464	5631	
	% RMVLS	30	48	63	74	82	18		
C	N	85	170	255	340	425	424	849	11
	RMVLS	1205	1961	2494	2983	3257	1186	4445	
	% RMVLS	27	44	56	67	73	27		
D	N	103	206	309	412	515	514	1029	11
	RMVLS	1050	1656	2221	2625	2908	1130	4038	
	% RMVLS	26	41	55	65	72	28		
E	N	38	76	114	152	190	187	377	6
	RMVLS	600	861	996	1064	1129	201	1330	
	% RMVLS	45	65	75	80	85	15		
WT AVG. % RMVLS		27	45	59	70	78	22		

N = NO. OF DIFFERENT LRU SERIAL NUMBERS

DATA SOURCE 3M DATA 1975–1985

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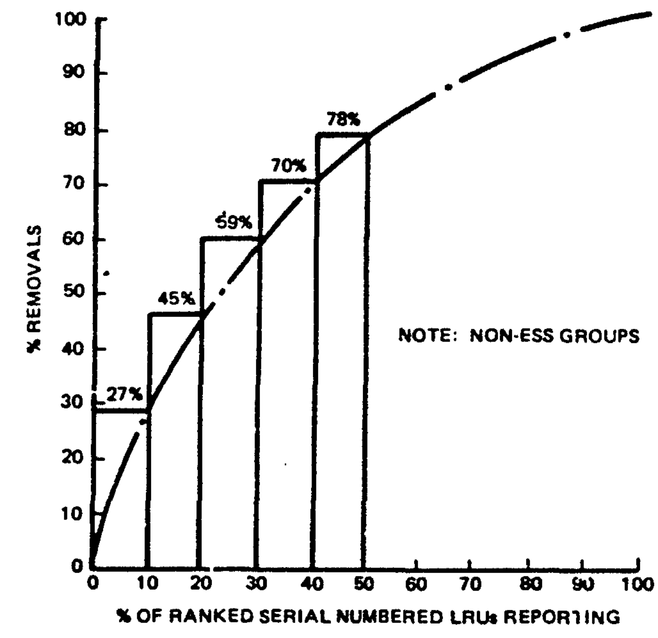

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Figure 12. Average distribution of removals by serial numbers reporting.

In establishing a bad actors program, the objective is to minimize the number of units that should be tested and to identify only those units which will provide the most potential benefit from an ESS effectiveness point of view.

To illustrate this aspect, consider an equipment with an MTBF of 100 hours, with a defective rate of two defects per unit, with 100 units in the field. If as before in the illustration of Subsection 4.1.2, the defects were to precipitate out within 1000 hours, at the end of 1000 operating hours per unit each unit would in effect have 12 removals. The process average μ would then be:

$$\mu = \frac{\text{Total Removals}}{\text{Total Units}} = \frac{R}{N} = \frac{1200}{100} = 12$$

If the specified MTBF of 100 hours were achieved, then the expected process average (μ_e) for 1000 hours would be:

$$\mu_e = \frac{T}{\text{MTBF}} = \frac{1000}{100} = 10$$

The comparison between the actual and expected would conclude that all units were defective, and that the actual exceeds the expected:

$$\mu \leq \mu_e$$

If however, the defectives were contained in only 25% of the units (25 units), then the frequency of removals would take on a distribution as shown in the table below:

N No. Units	R No. Removals	μ = R/N Process Avg
25	450	18
75	750	10
100	1200	12

The overall process average is still 12, but the defectives are isolated to only 25% of the population. This results in a typical frequency distribution as shown in Fig. 13.

The bad actor population will tend to have removals significantly higher than the process average. The removals for the individual unit criteria would then be:

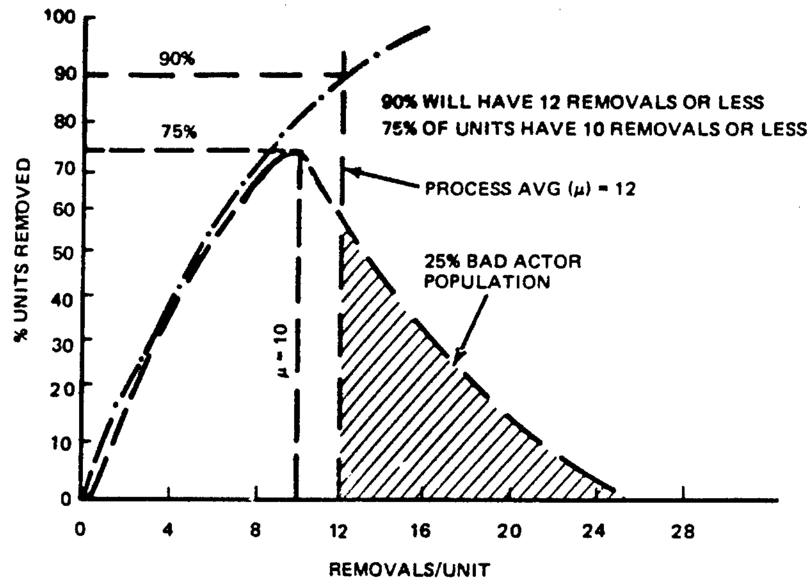

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Figure 13. Typical bad actor distribution effect.

$D \geq \mu$ = bad actor frequency

where: D is the next largest integer.

Any unit having D removals or more would be a candidate for selection. The un in the example therefore having 13 removals or more would be selected and wou effectively result in picking all 25 defective units.

4.1.3.1 Bad Actors Criteria - In selecting bad actors, the LRU serializatior reporting in the field maintenance system (AF/D056) provides the means to ident and determine the distribution of removals by LRU serial number. Figure 14 pr vides the distribution of removals per unit for each of the five non-ESS case hist populations for the last two years (1984-1985) of operation. In all cases, the distributions are skewed with 75% or better of the units having the average numb of removals (μ) or less and the remaining 25% providing the significantly more th the average number of removals. The table below summarizes the results giving t (μ) and (D) values, and the percentage of each of the units reporting populatio that would be selected for ESS testing.

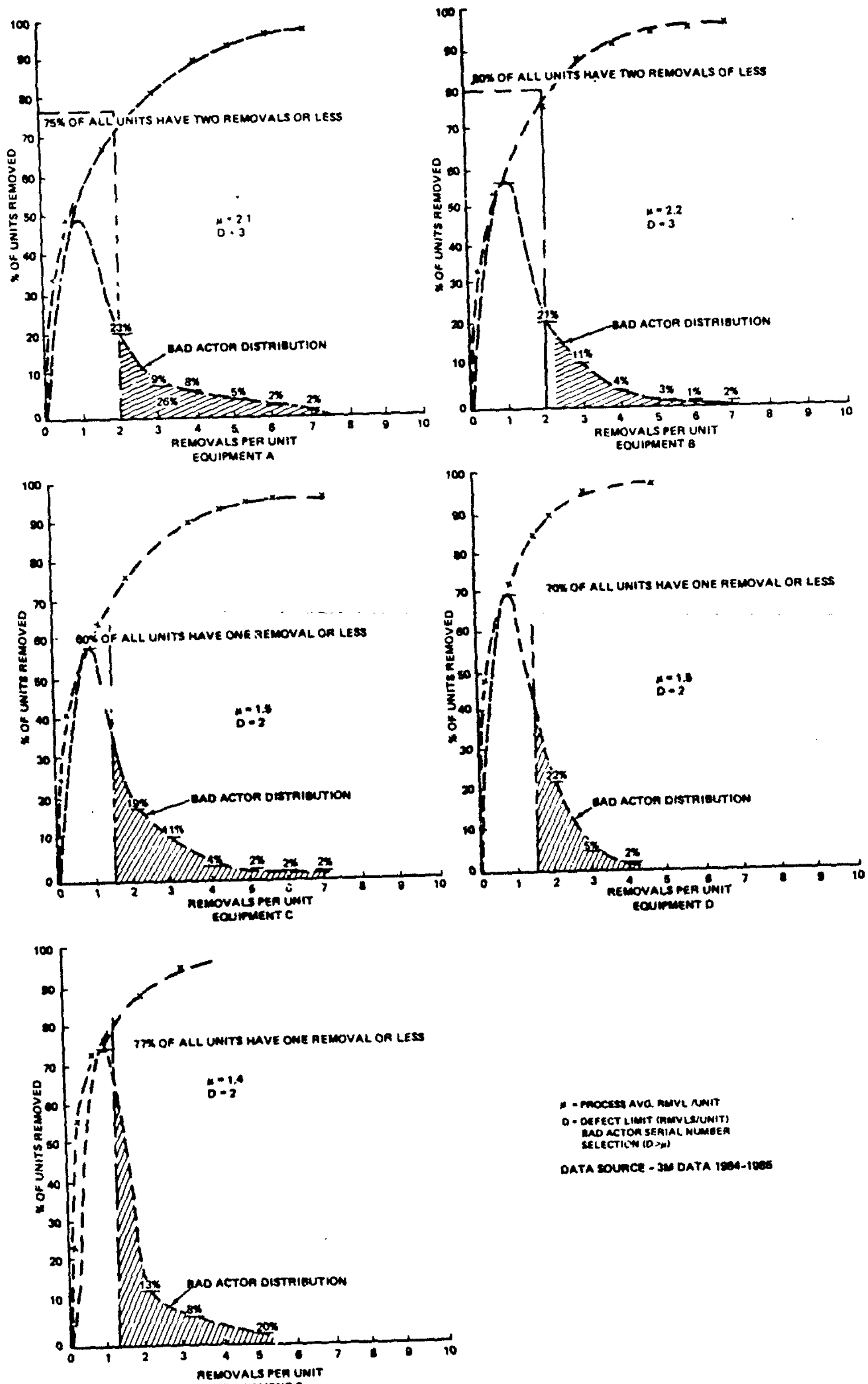

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Figure 14. Distribution of removals per unit.

Equipment	No. Units Reporting	Total Removals	μ	D	No. "Bad Actors" No. Units D > μ	% Units Reporting
A	390	821	2.1	3	101	26%
B	243	535	2.2	3	61	25%
C	345	518	1.5	2	104	30%
D	230	345	1.5	2	68	30%
E	109	153	1.4	2	26	24%

4.1.3.2 Bad Actor Selection Effectiveness - Figure 15 illustrates the improvement removal rate and removals/unit for the non-ESS populations if the bad actors were removed for screening. This is demonstrated by ranking the serial numbered units by removals for the 1984-1985 reporting period. The numbers reflected by the first column of the bar graph coincide with the statistics provided in the table of Subsection 4.1.3.1. The ESS level process average (μ) is based on the ESS population rate for the same period. This essentially says that the objective is to pull and screen the non-ESS bad actors in order to reduce the non-ESS population process average to as close to the ESS level as possible. The Bad Actor % rank reduction on the X axis is the rate at which the ranked serial numbers are being pulled. Therefore, if a population consisted of 100 units, 5% would result in the first 5 ranked serial numbers by removals being pulled, 25% would be the top 25 ranked, etc.

To reflect the impact of what the returned field ESS units might have on a real world scenario, an equivalent number of units were selected from the ESS population and added to the non-ESS population. Therefore, the subsequent columns are the rate at which the non-ESS units are pulled and replaced by effective ESS units until a normalized level was achieved.

As noted from the Y axes, the removal rate (MA/1000 FH) and process average (μ) (removals/unit) of the non-ESS population significantly reduce to a normalized level resulting in between 74 to 97% gain in the process average within 30 to 40% of the high ranked units.

The identifiable "D Limit" noted on each chart is the point in the rank distribution where the bad actor criteria is no longer exceeded (e.g., for equipment A,

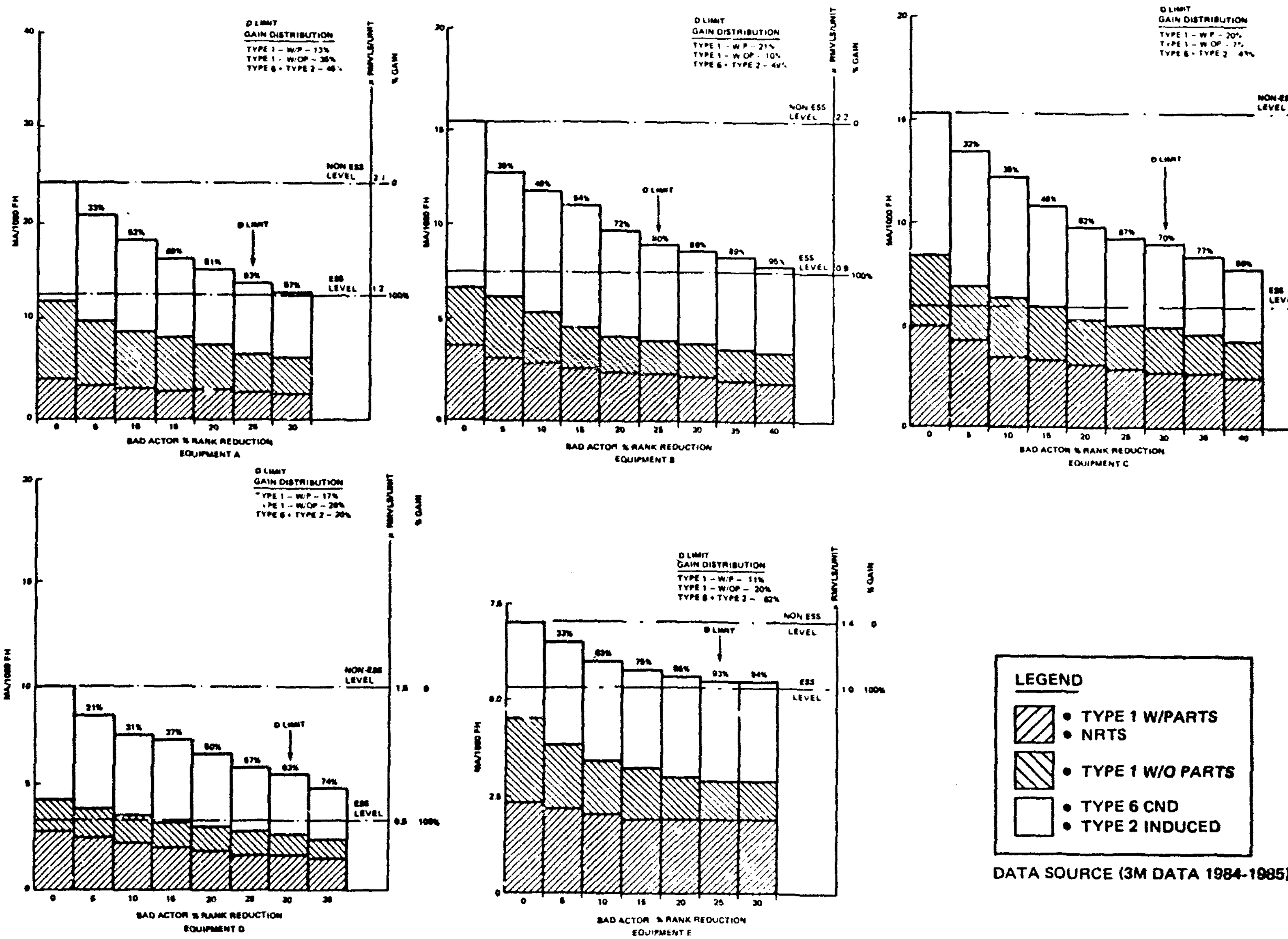

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Figure 15. Rate improvements & distribution as a function of bad actor reduction.

"D" was 3, at the "D limit" identified for equipment A is where the serial numbered units have two removals/unit or less). This occurs within 25% of the total serial number reporting and results in a 93% gain. This means that by pulling the bad actors in accordance with the selection criteria defined, the total non-ESS population process average is reduced to within 7% of the ESS population process average. The gain distribution in terms of Type 1 repairs with parts, Type 1 repairs without parts and Type 6 and Type 2 actions at the "D limit" is provided in the table for each equipment bar graph. The shading of the bars indicate the contribution of each type of action.

In effect, a 10 year old hardware is actually performing as well as the newer screened hardware. This implies that not only are the highest percentage of removals attacked via the bad actors, but the population of remaining good hardware approaches that of the new ESS population operational levels with the average gain in removal rate on the order of between 63% and 93% with only between 24% and 30% of the bad actor units removed and theoretically screened or otherwise replaced by screened units. Further, as noted by the gain distributions, the Type 6 actions are almost gaining by a margin of 2:1 over either Type 1 actions (with parts or without parts). The bad actor distributions have higher than normal false alarms and cannot duplicate conditions; this is highly conducive to ESS sensitive quality defects.

These observations on LRU bad actors conclude that this is an issue that warrants strong consideration and further investigation, since they definitely identify with high quality defect cases. Investigations at the SRU level cannot be accomplished, since SRU serialization is inconsistent and not separated to any degree in the maintenance reporting systems.

4.2 LEVEL OF ASSEMBLY TESTING

In dealing with level of assembly testing, it must be first understood that in a field scenario all process control is lost. Lot homogeneity, component and lower level of assembly in process controls do not exist, and any resemblance to these may have been long since lost due to interchangeability and configuration changes. Further, what is being dealt with is a top-down philosophy; the field unit is fully assembled and not sensitive to in-process control because the lower level population cannot be eliminated all at once, unless the unit is effectively overhauled with lower level screened assemblies and parts. Conversely, an LRU screen subjects the total

population of lower level assemblies to stress all at once. On a per repair basis, the effect of lower level ESS is virtually non-existent since only one defect can be eliminated at a time, and it becomes highly sensitive to:

- The true number of defectives that exist in the unit, which is not known
- The number of times the higher level of assembly is repaired in its lifetime.

The question that arises is whether or not lower levels of field screening can be justified not only on the basis of test effectiveness, but also as to their practicality from the point of view of defective reduction at the higher levels of assembly.

In none of the five case histories studied were parts or lower levels of assembly screened (other than as required by the standard part specification), nor were any of the logistic spare parts and assemblies that used in the field repair process of these equipment screened. As noted in the ESS data history profiles for the equipments, in Section 3, there has not been any degradation nor has it had any bearing on the removal rates over the last four to five years.

Table 8 provides the total number of SRU and lower level assemblies included in the LRU population for both non-ESS and ESS groups. The corresponding removal rates per component (λ) and equivalent MFHBR is provided. Based on the data of Table 8, Table 9 summarizes the effect that would occur if: (1) the component of a non-ESS LRU was replaced or repaired by a lower level ESS component, and (2) an ESS LRU was repaired by installing a non-ESS component. These effects are expressed as the percentage of improvement or degradation in removal rate. The corresponding average removal per LRU percentage is obtained by:

$$\% \text{ Improvement} = \frac{\lambda CN - \lambda CE}{\lambda LRU_N}$$

$$\% \text{ Degradation} = \frac{\lambda CN - \lambda CE}{\lambda LRU_E}$$

N = Non-ESS
E = ESS
C = Component

As noted by the defective rates per device (Table 8) and their effects (Table 9), the defective contribution becomes more and more complex as the level of assembly approaches the piece part. If, as noted the average rate of repair of a non-ESS

TABLE 8. Lower level of assembly removal rate distributions.

NON-ESS

EQUIP		REPORTING LRUs	TOTAL SRUs	TOTAL HYBRID/IC	TOTAL OTHER PARTS	AVG LRU RMVLS PER YR	AVG UTIL/LRU FH/YR
A	N	1106	54194	1.1×10^{6}	1.5×10^{6}	0.8	30
	λ	.0313	5×10^{-4}	2.5×10^{-5}	1.9×10^{-5}		
	MFHBR	32	2000	40,000	53,000		
B	N	970	20370	2.8×10^{5}	2.3×10^{6}	0.4	35
	λ	.0152	5×10^{-4}	3.8×10^{-5}	4.4×10^{-6}		
	MFHBR	66	2000	28000	225000		
C	N	849	43299	2.3×10^{6}	2.3×10^{6}	0.3	40
	λ	.0120	1.7×10^{-4}	3.2×10^{-6}	3.3×10^{-6}		
	MFHBR	83	5800	308000	301000		
D	N	1029	15435	1.7×10^{5}	1.3×10^{6}	0.3	33
	λ	.0109	5×10^{-4}	4.5×10^{-5}	6.2×10^{-6}		
	MFHBR	92	2000	22000	161000		
E	N	377	3016	5.2×10^{4}	5.1×10^{4}	0.5	56
	λ	.0018	1.8×10^{-4}	1×10^{-5}	1×10^{-5}		
	MFHBR	570	5532	100,000	100,000		

ESS

EQUIP		REPORTING LRUs	TOTAL SRUs	TOTAL HYBRID/IC	TOTAL OTHER PARTS	AVG LRU RMVLS PER YR	AVG UTIL/LRU FH/YR
A	N	587	28763	5.8×10^{5}	7.8×10^{5}	0.6	51
	λ	.0143	2.2×10^{-4}	1×10^{-5}	8×10^{-6}		
	MFHBR	70	4600	100,000	125,000		
B	N	453	9513	1.3×10^{5}	1.1×10^{6}	0.4	66
	λ	.0079	2.8×10^{-4}	2×10^{-5}	2.5×10^{-6}		
	MFHBR	127	3600	50,000	400,000		
C	N	432	22032	1.2×10^{6}	1.2×10^{6}	0.4	70
	λ	.0067	1×10^{-4}	1.9×10^{-6}	1.9×10^{-6}		
	MFHBR	149	10,000	520,000	520,000		
D	N	285	4275	4.8×10^{4}	3.6×10^{5}	0.3	105
	λ	.0036	1.8×10^{-4}	1.6×10^{-5}	2.1×10^{-6}		
	MFHBR	278	5500	62000	460,000		
E	N	158	1264	2.2×10^{4}	2.2×10^{4}	0.3	70
	λ	.0009	1.1×10^{-5}	5.4×10^{-6}	5.4×10^{-6}		
	MFHBR	1111	1100	185,000	185,000		

λ = REMOVAL RATE PER FLIGHT HOUR

MFHBR = MEAN FLIGHT HOUR BETWEEN REMOVALS

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TABLE 9. Improvement vs degradation of LRU effects as a function of single repairs with lower level assemblies.

EQUIP	% IMPROVEMENT/REPAIR NON-ESS LRU REPAIR BY ESS ASSYs			% DEGRADATION/REPAIR ESS-LRU REPAIR BY NON-ESS ASSYs		
	SRU	HYB/IC	OTHER PARTS	SRU	HYB/IC	OTHER PARTS
A	0.9	0.05	0.02	2	0.1	0.07
B	1.5	0.15	0.02	2	0.2	0.2
C	0.6	0.01	0.01	0.9	0.6	0.6
D	3	0.3	0.04	6.7	1.0	1.0
E	8.3	0.4	0.4	10.5	0.5	0.5

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LRU is in the range of 0.3 to 0.8 per year, and the percentage of improvement possible by a screened SRU is between 0.6% and 8.3%, it can be seen that it would take anywhere from 10 to 100 years to double the reliability of the LRU via repair by screened SRUs (assuming no further contamination). As the level of assembly gets lower this becomes even more compounded.

Conversely, if there are LRUs that have been screened and are being repaired by lower levels of assembly that have not been screened, the rate of decay is similarly slow since the rate of LRUs being repaired is lower. For this reason, the screened LRU population has shown no degradation over the last five years of field operation, as previously noted. This is without discounting state of the art improvements that have been incorporated in the parts over the last 10 years.

It should also be noted that for those cases where the LRU improvement or degradation is high per removal (e.g., equipment E with 8.3% to 10.5% rate change per removal) this occurs in the less complex (e.g., lower number of SRUs per LRU), higher reliability devices. Therefore a scenario of high density SRU removals per LRU should be given consideration as a potential candidate for ESS screening, especially if the failure rates are high. Figure 16 provides a decision making aid for identifying candidate SRU or lower levels of assembly effects on the LRU.

The abscissa (X axis) is the ratio of total removals contributed by the SRU or lower level of assembly. The right ordinate (Y axis) provides the potential improvement achievable of the SRU or lower level of assembly as a result of screening.

A 100% improvement is a virtual elimination of the component as a removal rate contributor. The left ordinate of the graph is the corresponding improvement that is achievable at the LRU level based on the achieved SRU or lower level improvement. As an example, if an SRU or lower level of assembly contributes 50% of the total LRU removals, eliminating it completely (or 100% improvement) cannot improve the LRU anymore than 50%, since you cannot gain more than you put in. Similarly, if the screen is only 50% effective, then the LRU improvement can only be 25%.

For these reasons, unless it can be justified, based on the graph of Fig. 16, the rate of impact at a lower level of assembly will have an impact at the LRU level, and there is no gain that can be realized by screening the lower levels of assembly. If there are relatively few SRUs or in the population of SRUs one which provides the predominant distribution of removals, then there is a potential that screening the SRU can achieve the corresponding removal rate improvement at the LRU level.

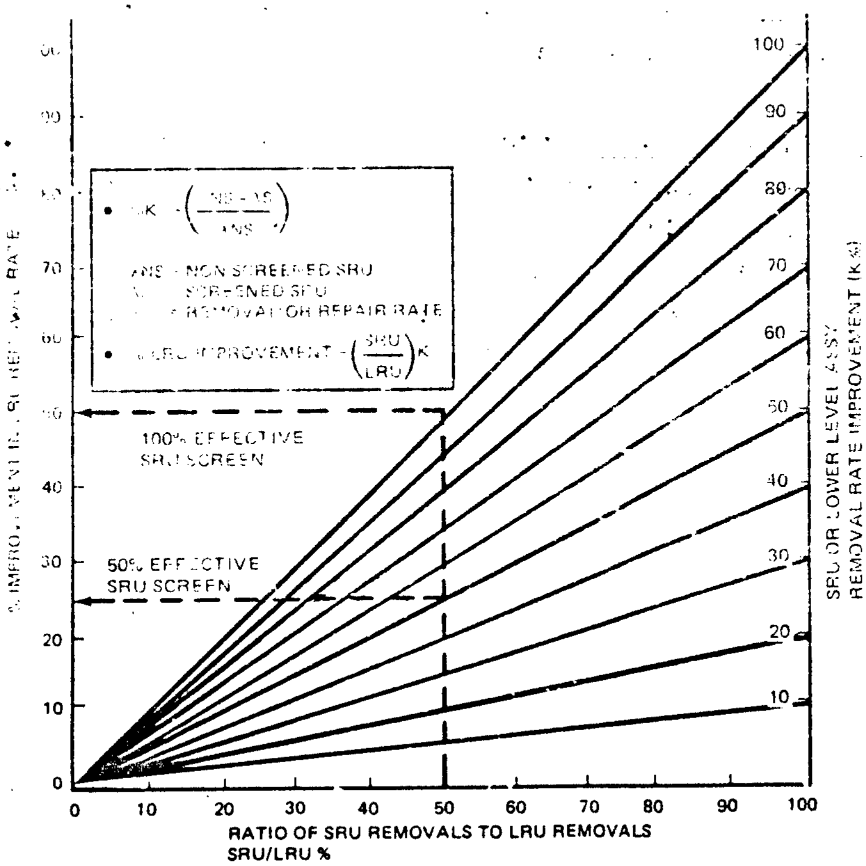

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Figure 16. Improvement in LRU removal rate as a function of SRU removal rate contribution.

These relationships, however, are non-existent in the field maintenance data scenarios and would require feedback on SRU repairs per LRU from the ALCs. Judicious screening of lower level (procured for logistic purpose) devices while at the supplier would ensure sound quality of lower levels of repair elements that would be entering "clean" LRUs.

4.3 EQUIPMENT AGE

Experience with equipment age, in terms of years of service and potential effects of ESS, does not exist to any formal degree or with sufficient background to support decisions one way or the other. Factors affecting equipment age include aspects of growth as a result of years of reliability improvement and upgrading, as well as degradation as a result of extended use and potential wearout. These factors must be counterbalanced to rationalize the potential effect from ESS, which in one case can significantly improve the growth characteristic of the device and in another case, degrade it in that it can potentially be destructive to the equipment.

From the detailed removal data generated for the five equipments, for both non-ESS and ESS populations over 10 years, growth patterns were developed using the Duane growth model (Ref 3) as described by the exponential growth rate equation:

$$\lambda_i = \lambda_T\left(\frac{T}{t_i}\right)^m$$

where λ_T = cumulative removal rate over (T) years
λ_i = initial removal rate at the initial year (t_i)
m = slope or growth rate parameter

This equation plots as a straight line on log/log coordinates.

Table 10 provides the results of the growth analysis and shows the removal rates and corresponding slopes for each equipment type.

The ESS groups exhibit no growth in removal rate over the four to five years that they have been operational. The non-ESS groups have some degree of positive growth, between 20% and 2%, over the 10 years of performance.

TABLE 10. Growth trend parameters.

EQUIP	POPULATION	λ_i INITIAL-RMVLS MA/1000FH	λ_T CUM-RMVLS MA/1000FH	M GROWTH RATE	T YRS
A	NON ESS	40.7	31.3	0.2	10
	ESS	14.3	14.3	0	4
B	NON ESS	15.6	10.4	0.17	10
	ESS	7.9	7.9	0	4
C	NON ESS	10.0	8.8	0.05	10
	ESS	6.7	6.7	0	4
D	NON ESS	8.2	7.8	0.02	10
	ESS	3.6	3.6	0	4
E	NON ESS	11.6	8.7	0.16	5
	ESS	5.4	5.4	0	5

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Growth projections were developed as shown in Fig. 17 (1) and (2) (for equipment A) to establish the effect that ESS would have on field performing hardware that was developing along the non-ESS growth line. The projected field ESS line is generated by projecting back the ESS level to what it might have been if it had been applied to the non-ESS population 10 years ago. At the point where the projected field ESS line intersects the normal non-ESS growth line, the effect of ESS would have actually no growth value.

The difference between the non-ESS removal line and the project field ESS line at any time (T years) provides the percentage of potential improvement in the removal rate that could be realized as a result of applying ESS at that point in the service life of the non-ESS LRU. Figure 17(3) provides the % improvement growth pattern lines for each equipment type. Equipments with little or no growth effect essentially conclude no change over time (equipments c and d). The percent improvement points are then plotted on the log/log coordinates for each equipment type, and a weighted (by removal rate density) improvement line as a function of age is developed. This line (Fig. 17 (4)) represents the potential improvements in removal rate that might be expected as a function of the service life of the equipment. The results tend to imply that hardware with greater than 10 years of field service would offer little if any growth potential due to ESS.

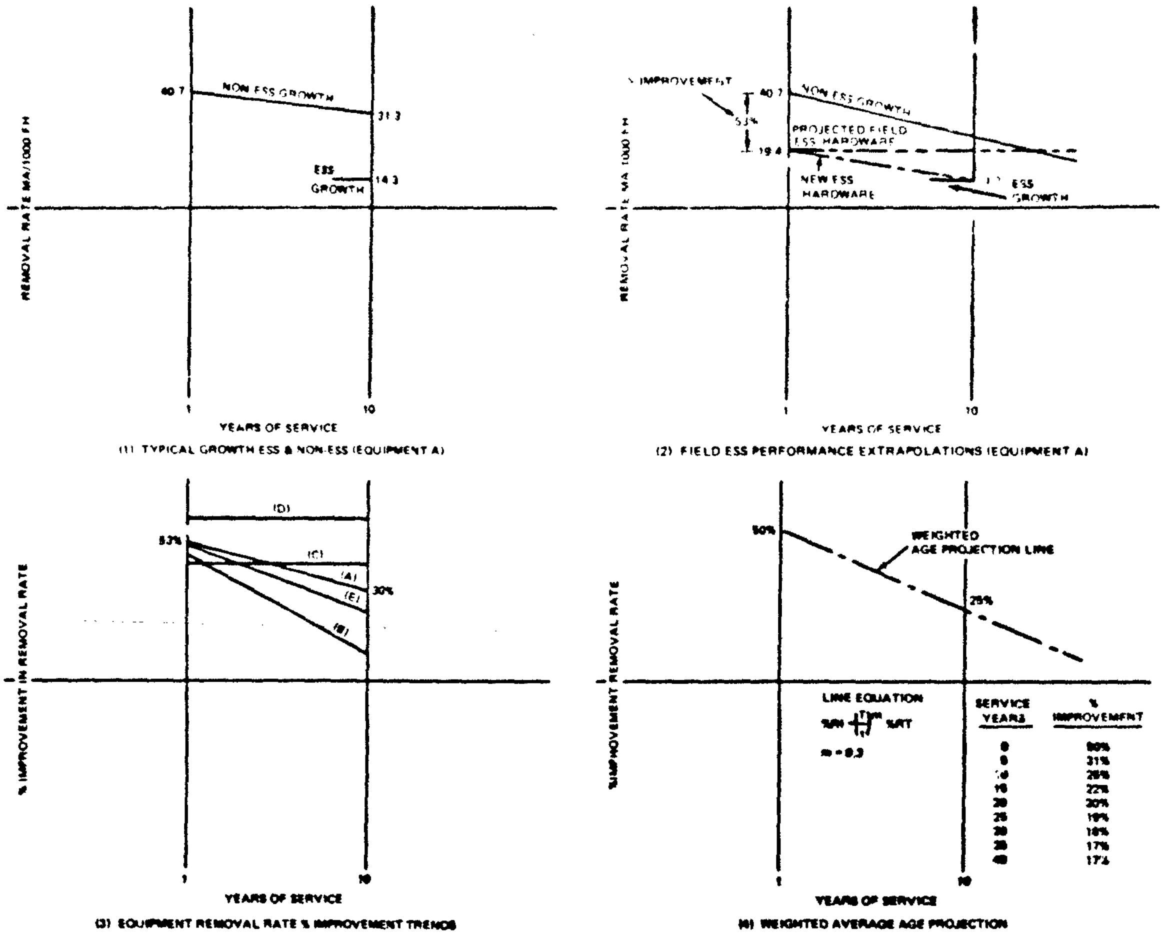

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Figure 17. Equipment age effect extrapolation.

4.4 SELECTION CRITERIA CONCLUSIONS

Conclusions developed from the selection criteria assessment have identified that:

- High removal contributor ranks provide the prioritization of equipment and LRUs to initiate the process of picking candidate hardware for screening. This is made possible by the fact that the total number of equipment removals from a weapon system is nominally contributed by a relatively small percentage of the total population of electronic equipment making up the system
- Bad actor selection provides a process for selecting a small number of LRUs identifiable by serial number, from the high contributor population which provide the highest percentage of ESS sensitive defectives

- SRU and lower level component screens are highly sensitive to the cont tion the level hardware is actually making to the LRU removal ra Selection at lower levels, for field screening, must be carefully assess establish that the scr. en will have an impact on the LRU on a per re basis
- Comparisons of removal rates (MTBR) to predicted or specified reliabi (MTBF) provide some insight to potential candidates in that the latent defects will suppress the true failure rate. This is particularly signif for small population systems, e.g., ground radars, ground test equip etc., where processes such as bad actor selection are not feasible. Th crimination ratio of $\frac{MTBF}{MTBR} > 1$ indicates potential candidate selection. The greater the magnitude, the greater the possibilities
- Equipment age and growth effects cannot be clearly quantified. Extro tion and averaging of growth experience curves of the five case histo tend to indicate that LRUs tested beyond 10 years of age offer lit improvement benefit as a result of screening. This cannot be supporte the study's case history ESS population, since all equipments tested v new and not field deployed. The nature of age effects can only l determined as a function of experience factors, which up to this time not been available.

5 - ESS TEST PROFILES

5.1 BACKGROUND

In 1957 the Advisory Group on Reliability of Electronic Equipment (AGREE), created in 1952 by the Department of Defense Research and Development Board to "monitor and stimulate interest in reliability and recommend measures that would result in more reliable equipment," published its recommendations. These included specific requirements for establishing environmental test profiles to be used during reliability demonstration testing. It was also suggested that these same conditions be utilized for acceptance testing for electronic hardware. Vibration was established as one of the environments and was limited to a sinusoidal excitation of ±2g at a fixed non-resonant frequency between 20 and 60 Hz. This form of vibration persisted for years and was used, with few exceptions, in the majority of electronics and avionic equipment acceptance tests conducted.

Evolving from the McDonnell Douglas Mercury and Gemini manned spacecraft programs, random vibration was utilized to more effectively screen workmanship defects. The unprecedented success of the Apollo manned space program, attributable in large measure to the intensive test program (Ref 4), generated some new thinking in industry and the military concerning the utilization of effective testing (including random vibration) in achieving reliability requirements. Skeptics still maintained that, while those techniques might work for Apollo whose vehicles were essentially "one shot" devices, they probably would not be effective for hardware (such as aircraft avionics) which had to survive thousands of takeoff, flight, and landing hours. Grumman decided at this time to investigate the merits of sine and random vibration testing. It appeared that random vibration, which provides simultaneous excitation of many modes in contrast to the single frequency sine test, must be more effective in disclosing manufacturing defects.

In 1972, Grumman embarked on an investigation to determine the effects of environmental stimulation of workmanship and manufacturing defects typically found in avionic equipment. The primary objective of this research was to develop a test embodying those environmental screens which were most effective in detecting latent

defects in contemporary hardware. As seen in Fig. 18, a major conclusion reached in an earlier Air Force study (Ref 5) conducted by Grumman shows that vibration and temperature are responsible for the majority of environmentally related field problems. Experience also indicates that workmanship defects respond to these same environmental stimuli as a function of their particular sensitivity.

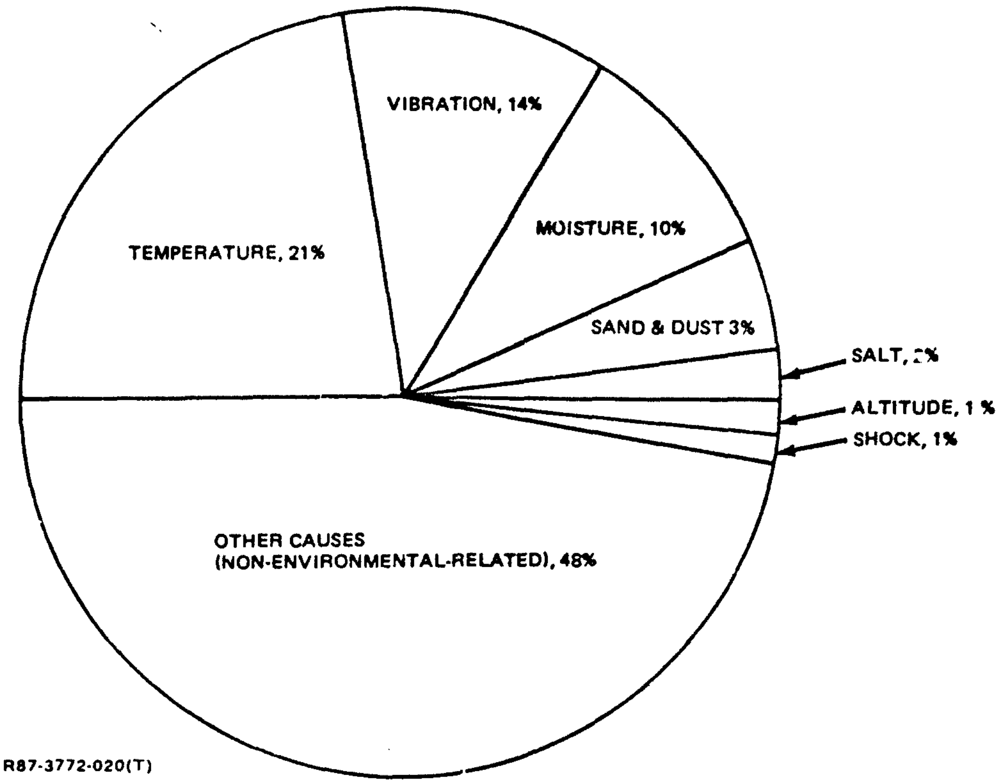

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Figure 18. Total field failure distribution.

5.2 RANDOM VIBRATION INVESTIGATIONS

The sparsity of random vibration application data prompted Grumman to initiate a laboratory test evaluation structured to directly compare the effectiveness of sinusoidal and random vibration (Ref 6). A technical approach was conceived wherein the time-to-failure of typically occurring defects could be examined under controlled environmental conditions and selected durations. Typical workmanship defects, representing 80% of manufacturing problems found in avionic hardware, were selected from space and aircraft test and field failure data. These defects were simulated in quantities considered sufficient for analysis and were inserted into a typical avionic "black box." The test plan provided for a total of 100 simulated defects to be included in any given test matrix of different levels and durations.

Tests were conducted using sine fixed frequency, sine sweep, and random vibration excitations at different levels and for varying periods of time. Figure 19, as an example, depicts the matrix for sine sweep testing. Similar matrices were developed for sine fixed frequency and random vibration tests.

TEST SERIES 1 – SINE SWEEP
5 – 500 – 5Hz

LEVEL	DURATION		
	LOW-10 MIN	MED-30 MIN	HIGH-60 MIN
LOW ±1.5g	•	•	•
MED ±5g	•	•	•
HIGH ±10g	•	•	•

EACH TEST – 100 FAULTS
(20 OF 5 TYPES)

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Figure 19. Typical test matrix.

The results clearly indicate that random vibration, at a $0.04g^2/Hz$ level (Fig. 20), was significantly more effective than either of the sinusoidal tests. Figure 21 compares the effectiveness of the three forms of vibration for two of the most common defect types at levels "typically" used in acceptance testing. The results of this comparison are obvious. Figure 22 compares the "typical" random level with a ±5g level for each of the sine type tests. The results show that even at increased levels, the random vibration is more effective (for a given fault type) than sine fixed frequency or sine sweep. In the Fig. 23 comparison, levels of vibration up to

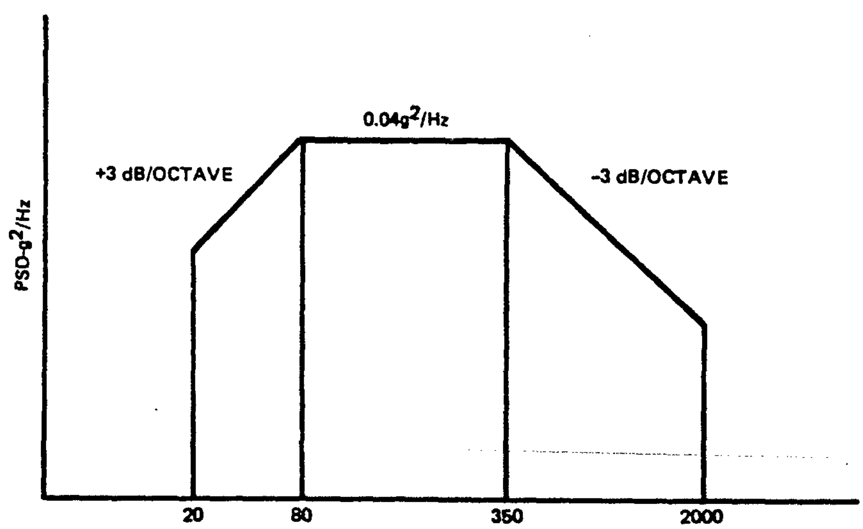

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Figure 20. Random vibration spectrum.

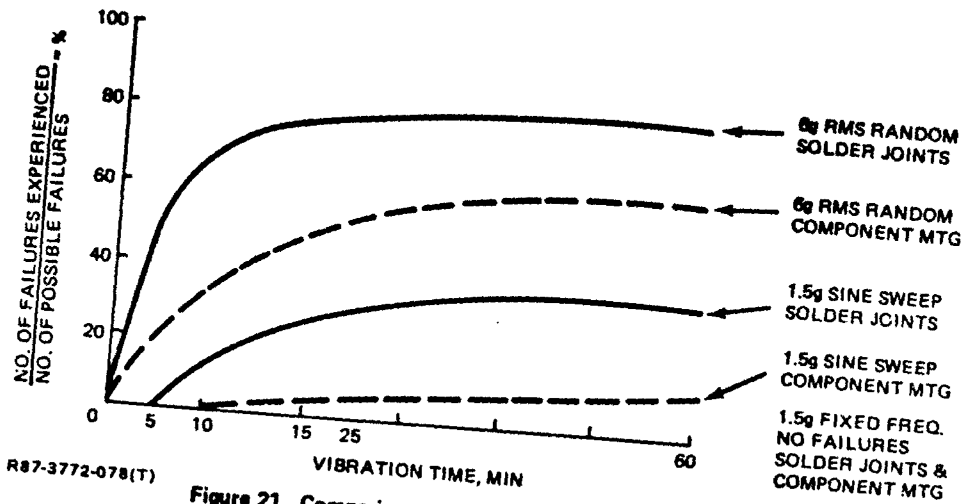

Figure 21. Comparison of typical acceptance test levels.

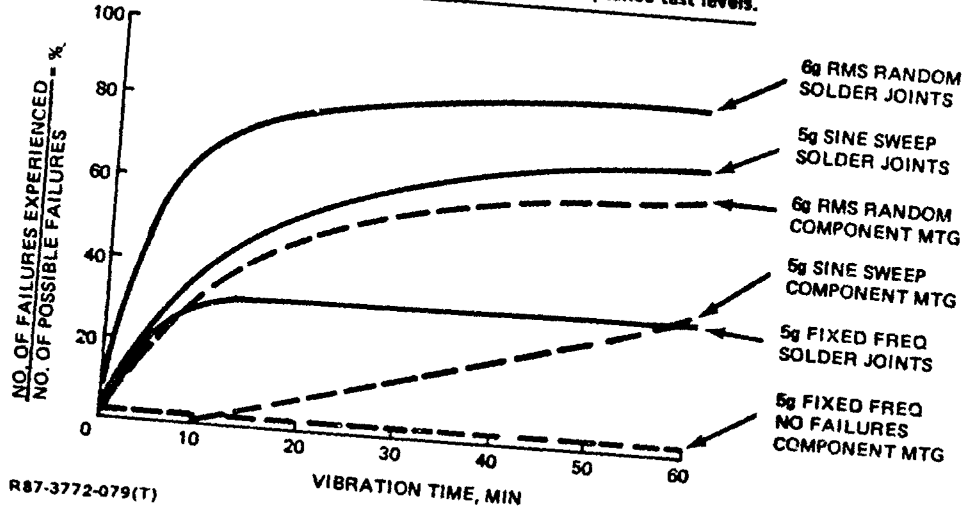

Figure 22. Comparison of typical random & increased level SS/SF (5 g).

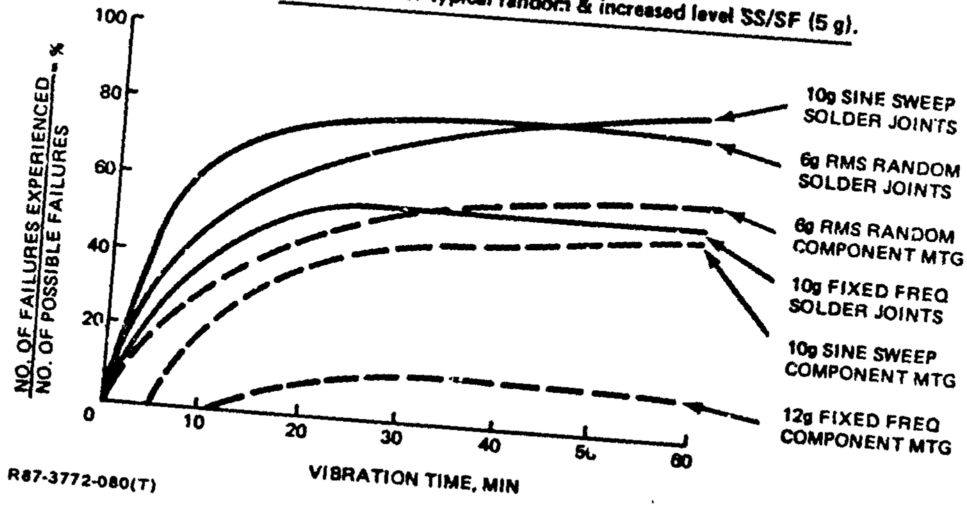

Figure 23. Comparison of typical random & increased level SS/SF (> 10 g).

and exceeding qualification were used for the sine type of test. Although the sine sweep test was close to the "typical" random test or both failure types, it required durations of approximately one hour at qualification levels (±10g) to achieve this type of effectiveness. Testing production hardware at these levels and durations would certainly present a potential fatigue problem and would never be utilized in an acceptance test. The "typical" random vibration spectrum achieved its maximum effectiveness in only 10 minutes of testing.

Some concern was expressed that the application of a $0.04g^2/Hz$ random vibration level would cause fatigue and structural damage if applied to equipment even if that equipment had proven its structural integrity during qualification tests. During the advanced development program conducted by Grumman, a correctly manufactured example of each fault type was inserted in the test article as a control. Even after many hours of exposure at the $0.04g^2/Hz$ level, not one of these correctly manufactured examples failed. Further, equivalency analyses performed by Grumman and Wright-Patterson Air Force Base indicate that the $0.04g^2/Hz$ level is much less severe than qualification levels currently used. In his paper, (Ref 7), Dr. Dreher points out that a fatigue test level of $W_F = 0.10g^2/Hz$ is equivalent to a sinusoidal level of only $G = \pm 2.5g$. He further indicates that it takes a level of $W_f = 1.6g^2/Hz$ to be equivalent to a ±10g sinusoid. It should be noted that these equivalencies, developed analytically, apply universally to any type of equipment undergoing vibratory excitation.

Additionally, Grumman has had extensive experience in the use of random vibration as an acceptance test, workmanship screen and/or troubleshooting aid. During the Lunar Module (LM) space program, over 7,000 tests were performed. In all the history of random vibration applied at the $0.040g^2/Hz$ level at Grumman, no known instance of degradation or subsequent field failure attributable to the vibration test has occurred.

The development of an effective random vibration screen was a significant milestone in the evaluation of environmental acceptance testing. A review of flight hardware application data (both test and field) indicated that exposure to the random vibration test spectrum, more than doubled the equipment's MTBF. It should be noted that the random vibration applied was only 10 minutes in duration in one di-

rection, compared to many hours of sine vibration formerly used. While the development of the new vibration screen was proven to be more effective and shorter than tests previously employed, it is the time required for thermal cycling which actually drives the test costs.

5.3 THERMAL CYCLING INVESTIGATIONS

During 1976 the program evaluated the effects of various thermal cycling rates on defects into avionic equipment at the black box level. The purpose of this evaluation was to establish both the more effective cycle and the optimum exposure duration required. Data could be obtained on the slow thermal cycling normally used for acceptance of LRUs, but similar information was not available for more rapid temperature change effects. A laboratory program was therefore developed to examine the time-to-failure of typical defects under controlled thermal conditions. Seven of the most common generic types of workmanship faults that were presumed sensitive to temperature and found in field hardware were selected and stimulated in quantity. These faults were inserted into a typical LRU and a series of tests was conducted under various thermal cycling conditions.

In the first test the specimens were exposed to the most rapid achievable thermal cycle in a standard temperature chamber. During this test the air temperature was varied at an average rate of approximately 5°C (9°F)/min. between -54°C (-65°F) and +71°C (+160°F) (Fig. 24). Each thermal cycle required 1.5 hours to complete.

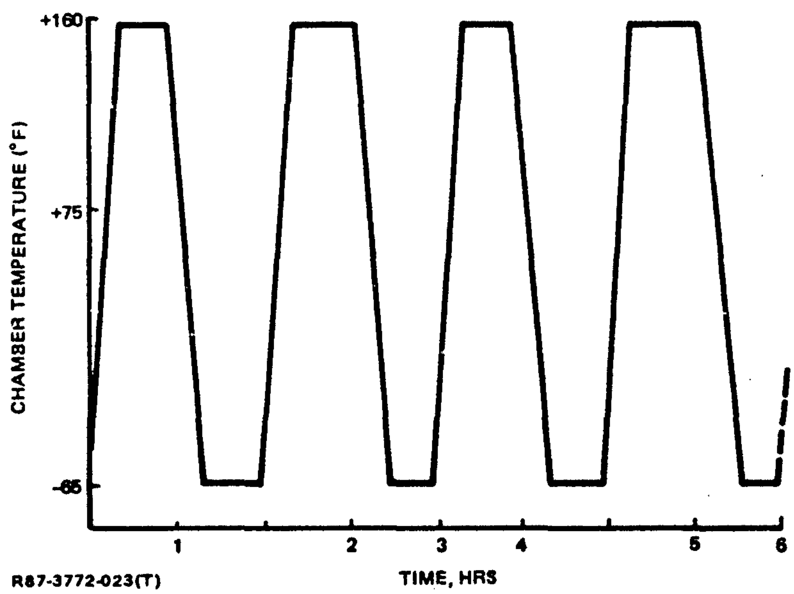

Figure 24. Rapid thermal cycle.

The test was continued to a total of 168 hours and during this period each fault was energized and monitored on a full-time basis. Any failures occurring during the exposure period would be instantly recognized by the monitoring circuitry, and a lamp lit and latched for either intermittent or permanent anomalies. This arrangement permitted unattended operation (nights and weekends), thereby greatly facilitating the effort and permitting maximum use of available calendar time.

Prior to initiating the second test, all faults were refurbished and returned to their original state. The second test was then conducted by exposing the specimens to a thermal cycle which was the standard generally now used by industry in acceptance tests. The rate employed was approximately 1.4°C (2.5°F/min. and air temperature was varied between -54°C (-65°F) and +71°C (+160°F) (Fig. 25). Each cycle required six hours to complete. This cycle was approximately 25% of the rapid cycle in terms of cycles/unit time. Monitoring, fault detection and duration of test were identical to those employed during the first test.

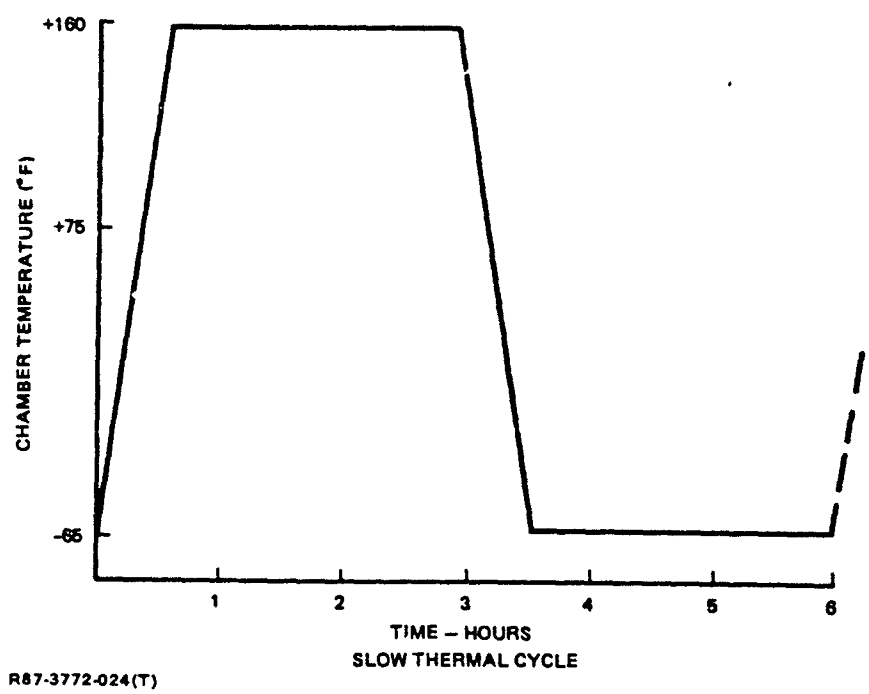

Figure 25. Thermal cycle.

Figure 26 presents two curves which summarize the test results for the fault types and compare the relative effectiveness of the two thermal cycles imposed. The rapid cycle detected three times the number of faults disclosed by the slow cycle

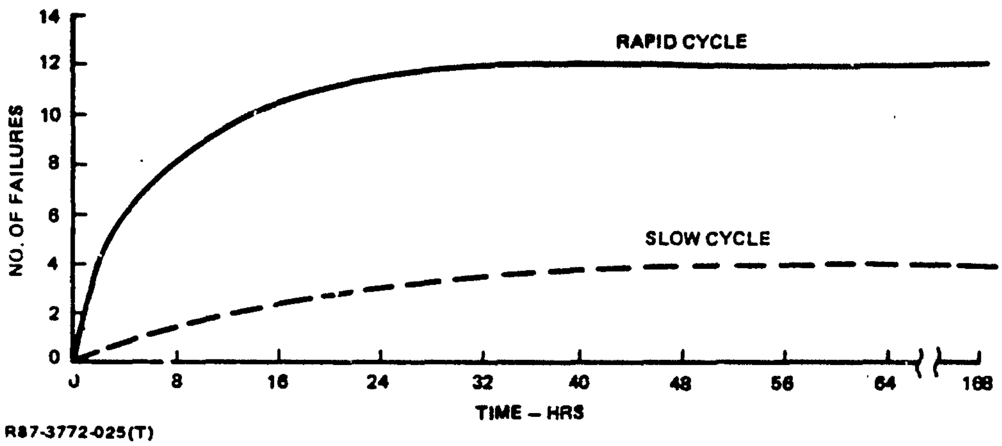

Figure 26. Test results – slow vs rapid cycle.

within the same time period. Further, the point of diminishing exposure time efficiency was 40 hours for the rapid cycle compared to approximately 50 hours for the slow cycle. Of even more significance is the fact that only approximately 40 hours of thermal cycling at a rapid rate are required to remove certain latent workmanship defects compared to the 200 hour average duration test generally employed by industry. Testing beyond the 40 hour point produces little, if any, additional screening of these samples.

5.4 OPTIMIZED ESS TEST SEQUENCE

Grumman embarked in 1977 on an investigation to measure the efficiency of ESS testing if one were to combine random vibration and rapid thermal cycling and also optimize the sequence of its application.

Initially, a tradeoff study was performed to investigate sequential versus combined environmental exposure. Combining the two environments did not offer any technical advantage, i.e., no synergism was apparent. Furthermore, the cost incurred by dedicating a random vibration system to production acceptance testing clearly prohibited combining the environmental exposures for acceptance testing. The study therefore concentrated upon a sequential schedule of rapid thermal cycle and random vibration applied at the LRU level. Additionally, the possible advantage of "prescreening" complex/high-problem PCBs prior to their installation in a black box was very attractive. Again, a study was initiated to investigate possible

methods of applying the environments and monitoring PCB performance without the need for an enclosure. Although applying rapid thermal cycling and monitoring the assembled boards seemed easily effected, the problems associated with applying random vibration without special holding fixtures were of such a magnitude as to preclude its further consideration. It was therefore decided to conduct laboratory experiments in which PCB assemblies were exposed to rapid thermal cycling only.

As in previous investigations, the technique utilized was to purposely insert faults into the test equipment and then determine which environmental exposure most effectively stimulated these faults.

It should be noted that for each fault inserted, a correctly manufactured example of that defect was also included in close proximity to the fault to provide a positive form of test control. Any failure, or evidence of fatigue of the correctly manufactured examples, would indicate overly severe environmental exposure and dictate that a less stringent test be developed. No failures occurred, nor was there any evidence of fatigue damage of any of the good examples inserted.

- LRU Level - during the rapid thermal cycling tests conducted, a total of 10 defects were detected. The application of random vibration detected an additional five faults. It was interesting to see that the fault detect efficiency trends shown in Fig. 27 follows exactly the same behavior patterns measured during the previous independent rapid-thermal cycling and random vibration investigations. That is, after approximately 40 to 50 hours of rapid thermal cycling and after four to 10 minutes of random vibration, any additional testing was not cost effective. It should be noted at this time that the fault types for this investigation were selected predominantly for their thermal sensitivity. However, for certain types of defects, temperature and vibration inputs each provide a certain degree of stimulation. The increase in defects due to vibration becomes significant when viewed in the the above comments, and a test conducted utilizing both random vibration and rapid thermal cycling could conceivably be run in a shorter time period with the same effectiveness achieved. Since thermal cycling costs "drive" total acceptance test costs, a substantial savings would be realized
- PCB Level - testing was performed at the PCB level to determine if thermal screening efficiency would be better than at the LRU level. That testing was limited to thermal cycling only. The results obtained during this testing phase did not follow any of the previously established patterns. Only seven

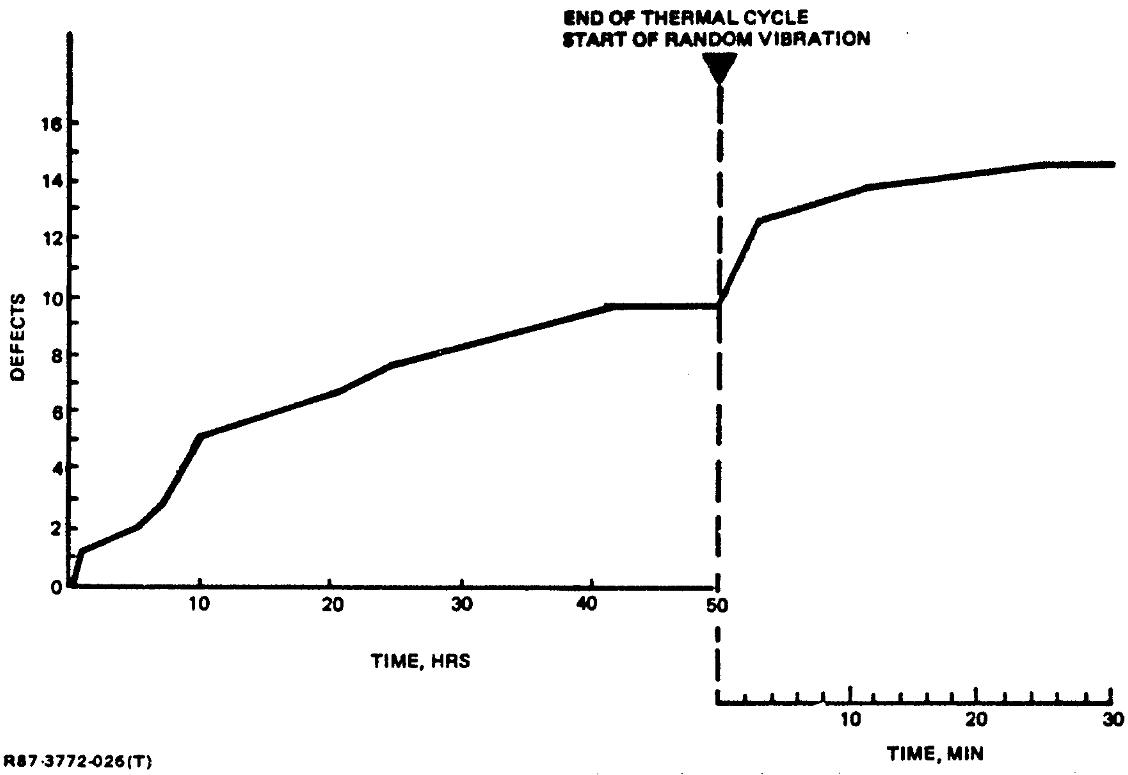

Figure 27. Black-box level test results.

defects were disclosed, six within the first 10 hours. However, all defects were detected on the two adjacent boards at the front of the test "housing." The boards were rotated to investigate the uneven failure distribution and an additional seven hours of rapid thermal cycling was applied, but no additional faults were detected. Although the uneven failure distribution could not be explained, the fact that the total number of failures detected was significantly less than those disclosed during LRU tests indicates that rapid thermal cycling testing at this level should not be considered in lieu of LRU level tests. Apparently the thermal delta between faults and surrounding air is not as great when boards are directly exposed to temperature cycling as that when the boards are contained within a black-box enclosure. As a result, thermal stresses which produce physical stresses are not adequately developed. As the years progressed, further investigations were conducted to continue to measure the efficiency of ESS testing as it related to the sequence of environmental application. The results of these investigations are summarized in Table 11.

TABLE 11. Environmental exposure optimization efforts.

YEAR	ENVIRONMENTAL EXPOSURE	% EFFECTIVE
1976	STANDARD THERMAL CYCLING (168 HOURS) RAPID THERMAL CYCLING (168 HOURS)	10 30
1977	RAPID THERMAL CYCLING (50 HOURS) THEN RANDOM VIBRATION (10 MINUTES)	42
1978	RANDOM VIBRATION (5 MINUTES) THEN RAPID THERMAL CYCLING (50 HOURS) THEN RANDOM VIBRATION (5 MINUTES	60
1979	RANDOM VIBRATION (10 MINUTES) THEN RAPID THERMAL CYCLING (50 HOURS)	47

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- Military Standard Development - the culmination of all the latter Grumman investigations was realized when MIL-STD-2164(EC), Military Standard, Environmental Stress Screening Process for Electronic Equipment, was developed in April 1985 for the Navy Electronics Command. It should be noted that the random vibration and rapid thermal cycling requirements had been successfully applied at various stages on Navy avionic procurements since 1972.

The significance of these new ESS requirements is summarized in the Standard's Forward: "The current emphasis on reliability and hardware design integrity has resulted in an increased potential for providing a basically sound and inherently reliable design. As this potential has increased, so has the complexity and density of packaging of contemporary electronic equipment. This complexity and density amplifies the ever present problems of detecting and correcting latent manufacturing defects. The occurrence of a malfunction due to poor workmanship incurs extremely high maintenance costs after the equipment has been deployed. The fact that the unit had been fully qualified and demonstrated a contractual mean time between failures in the laboratory becomes meaningless when such a failure results in loss of life or mission.

Specifications, standards and guidelines currently exist for development, and qualification testing. No similar documentation exists for the Environmental Stress Screening (ESS) Process; consequently, gross inconsistencies in approach, coupled with test ineffectiveness, result in latent defects causing failures in delivered equipment. This standard defines the approach and method to be used for Environmental Stress Screening of electronic equip-

ment so that latent defects may be located and eliminated before the equipment is accepted."

The intended application of MIL-STD-2164(EC) is for use on newly developed equipment. The generic test levels and durations are included in the design requirements analyzed by the equipment manufacturer. The designer of an electronic package has to take into consideration all of the static and dynamics loads associated with operation, accelerated environmental testing, reliability, storage, shipping, and ESS acceptance testing. Given due consideration to the above requirements, an equipment designer can produce an LRU design that will fulfill the contractual obligations of the procuring activity, without the need to tailor environmental requirements.

Therefore, utilizing the above philosophy, we have demonstrated on production equipment that it can be subjected to the MIL-STD-2164(EC) requirements without experiencing any structural or major operational performance problems.

5.5 STUDY RESULTS

As a result of the ESS benefits realized on avionic equipment, Grumman was able to introduce the new random vibration and rapid thermal cycling screening environments to several in-house aircraft contracts. Because of the contractual problems of the five LRUs evaluated, only two were exposed to random vibration, but all five were subjected to the rapid thermal cycling. In any event, it was possible to measure the affects of the new ESS requirements on equipment already in field environment which had been subjected to non-ESS, i.e., sinusoidal vibration and slow thermal cycling, acceptance tests. Then this same type of equipment in a subsequent contract was exposed to the new ESS levels. A comparison of these ESS test characteristics is described in Table 2 of Subsection 3.1.

As a part of this investigation a complete analysis of the Navy failure rate and maintenance actions reports for these equipment was made. As described in Section 3, the data included over 10 years of activity of the non-ESS and five years of the ESS on the identical type equipment. For comparison purposes, an analysis was performed on all five LRUs showing the number of total actions for the last two years of assessment for both the non-ESS and ESS equipment. The results (Table 12) clearly show a positive reduction in removals when ESS was applied for every LRU examined in this study by a substantial margin.

TABLE 12. ESS effectiveness.

EQUIPMENT	NON-ESS MFHBR	ESS MFHBR	% IMPROVEMENT
A	32	70	119
B	66	127	92
C	83	149	80
D	92	278	202
E	570	1110	95

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5.6 ANALYSIS OF RESULTS

The advantages of applying the generic environmental stress screening have been well documented. Within Grumman and at our subcontractor's facilities, use of the generic levels and durations are working very successfully on all new design electronic equipment procurements.

For this study because the potential ESS candidate equipments in all probability were never designed for random vibration or rapid thermal cycling, some form of tailoring must be considered. It should be pointed out that our experience has taught us that this does not mean the equipment is incapable of withstanding the latter environment. In most situations this same equipment probably has been operating in this type of environment, i.e., in a jet aircraft experiencing rapid temperature changes and random vibration, without any structural damage.

In some cases, performance anomalies (such as out of tolerance conditions) did exist when the generic levels were applied to some of the early vintage electronics. It became apparent after instrumenting these test units, that if the response acceleration exceeded an amplification factor of 10, a performance anomaly would become evident. In these instances it was necessary to tailor the random vibration levels by notching at certain frequencies to minimize the operational problems associated with marginal component or a subassembly installation. An actual example of this technique for a typical LRU with instrumentation installed at various locations is described in detail as follows:

(1) Conduct a ±3g sine sweep and measure the ratio (response/control) at the desired locations (see Fig. 28 for typical response)

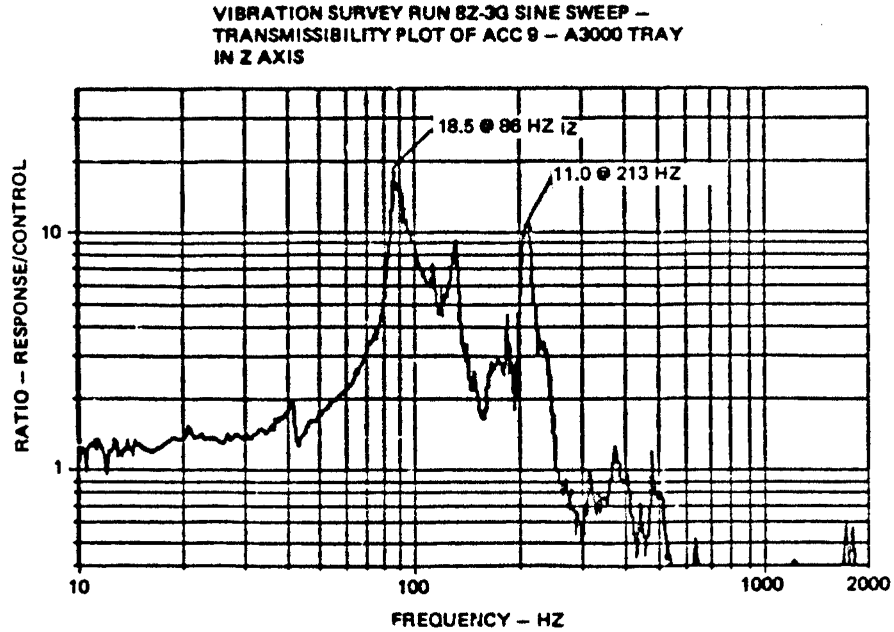

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Figure 28. Vibration survey ±3g sine sweep transmissivity plot in Z axis.

(2) Record measured vibration amplification factors exceeding 10, e.g.,

Accelerometer No.	Location	Amplitude-3G Input
1	Bottom of A1000 Assy	11 @ 104 Hz
3	A4000 Tray	16 @ 104 Hz
9	A3000 Tray	15 @ 80 Hz
10	A8000 Tray	20 @ 100 Hz
13	Top of A6000 Assy	16 @ 103 Hz
7	A5000 Assy	10 @ 196 Hz

(3) Calculate the required random vibration notching to reduce amplificat to 10, e.g.,

79 to 95 Hz - Max Ampl = 15 PSD = (10/15) x .04 = .0267 GSQD/H
95 to 104 Hz - Max Ampl = 20 PSD = (10/20) x .04 = .0200 GSQD/H
104 to 113 Hz - Max Ampl = 14 PSD = (10/14) x .04 = .0286 GSQD/H
Above 113 Hz - No notching done in this freq range.

(4) Incorporate notching of the generic 6.0G RMS random vibration test s trum as in Fig. 29:

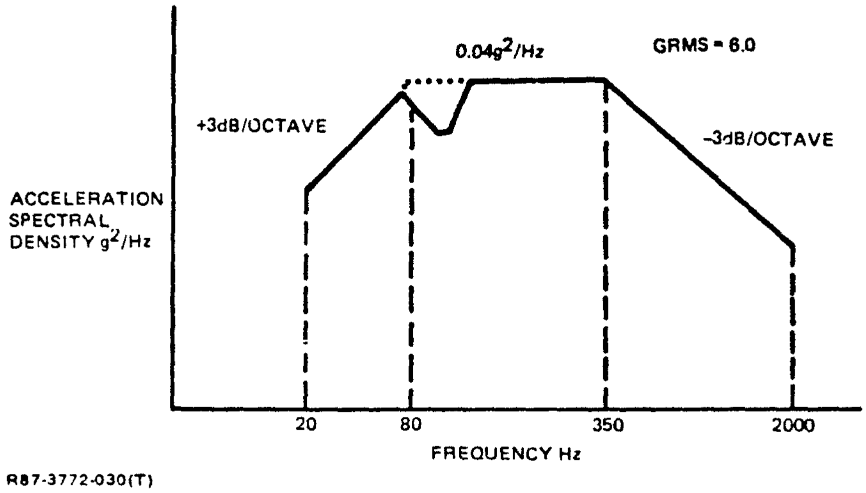

Figure 23. Notching of random vibration test spectrum.

With respect to the rapid thermal cycling requirements, the only tailoring necessary is to set the temperature limits of the chamber so as not to exceed the operating temperature at which the test article was environmentally qualified.

Due to the numerous analytical ESS studies and tests conducted, we have developed Table 13, which summarizes the recommended ESS regimen to be used for field equipment. These guidelines are based on tailoring the levels and procedures described in MIL-STD-2164(EC) and should be directly applied to either the LRU or drawer level of assembly. Our field equipment ESS investigations indicated that there was little advantage to perform both a 40 hour pre-defect free and a 40 hour defect free thermal cycling test. The test data indicated that the previous use environment stimulated the major workmanship and manufacturing problems, substituting the need to do a pre-defect free period. To satisfy the defect-free requirement, it was thus decided that if the candidate equipment experienced an ESS failure during thermal cycling and it was replaced immediately after that cycle, there should be an adequate number of defect free cycles accrued within the fixed 40 hour period to satisfy the defect-free requirement. This considerably reduces the test time and its associated costs.

TABLE 13. Recommended ESS guidelines.

RANDOM VIBRATION	
• POWER SPECTRAL DENSITY	20-80 HZ @ + 3dB/OCTAVE 80-350 HZ @ .04 GZ HZ 350-2000 HZ @ -3dB/OCTAVE
• AXES STIMULATED	ONE AXIS (PERPENDICULAR TO PRINTED WIRING BOARDS)
• DURATION OF VIBRATION	5 MIN AT START OF TEST
• POWER ON (EQUIPMENT OPERATION)	YES
• EQUIPMENT MONITORING	YES
THERMAL CYCLING	**EQUIPMENT BOX, OR DRAWER (LRU/LRM)**
• TEMPERATURE RANGE	OPERATING ENVIRONMENTAL QUALIFICATION LIMITS
• TEMPERATURE RATE OF CHANGE	5°C/MIN
• TEMPERATURE DWELL DURATION	BASED ON THERMAL SIGNATURE STUDY
• THERMAL CYCLING DURATION	40 HRS
• POWER ON (EQUIPMENT OPERATING)	YES
• EQUIPMENT MONITORING	YES
• ELECTRICAL TESTING AFTER ESS	YES (AT ROOM AMBIENT)

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6 - ECONOMIC ANALYSIS

6.1 INTRODUCTION

The application of ESS is universally recognized as a major technical expedient to remove workmanship and manufacturing anomalies in electronic equipment. The associated costs to perform ESS testing on new equipment procurements is generally easy to justify, primarily because the testing at the manufacturer's facilities. At that point in the development and eventually in production, all of the assets required, i.e., technical expertise, support equipment, manufacturing facilities and environmental test equipment, are available on site. However, once the electronics are sold off to the customer, the only resource he has is to send it back to the manufacturer while still under warranty or to repair it himself. Therefore the emphasis is to do as much screening upfront as possible to insure the reliability in that equipment is what it should be.

In the case of non-screened equipment, the problem the customer faces is how he economically justifies performing ESS on the thousands of electronic equipments in inventory. To this end, the rationale discussed in the preceding chapters of this study recommends that the solution is not to conduct ESS on all the electronics inventory. The solution is to select only those equipments which can be shown to have the highest potential for containing workmanship type defects. This selection criteria utilizes the maintenance information reported in AFM-66-1, and permits the user to determine where he should direct his engineering assets.

The next step in the selection process is to determine the ESS facility, environmental equipment, monitoring, and associated manhours to be able to see the whole picture before the final decision can be made. Thus the objective is to develop a procedure to determine the ROI for those electronic equipments selected as ESS test candidates. The cost methodology developed is described in Fig. 30 and shows the major ingredients required to determine if there is truly a cost benefit, i.e., ROI is adequate.

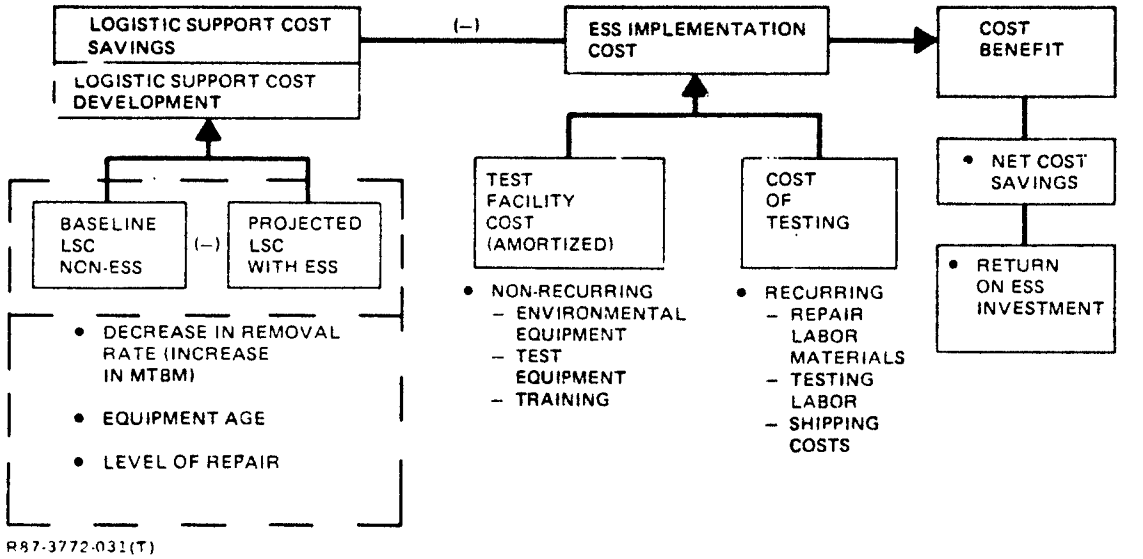

Figure 30. Methodology for economic analysis of ESS.

The financial return on ESS is the logistics support cost savings, which is th difference between non-ESS maintenance costs and those after ESS during the remainder of the life of the LRUs/SRUs to be tested. Logistic support costs are th result of a complex maintenance process the majority of which consist of the cost associated with the following:

(a) Spares required to replace failed units

(b) Depot level repairs

(c) Maintenance labor both on and off the primary system.

Figure 31 provides the basic formula for determining the ROI and is the resul of conducting numerous cost benefit trade-off studies which will be discussed in detail in the subsequent paragraphs.

6 2 LOGISTIC SUPPORT COST SAVINGS (LSCS)

The application of ESS results in the reduction of downstream Logistic Suppor Costs (LSCs) on LRUs and SRUs durir the remainder of their life. This is due to the expected decreased failure rate an improved reliability. ESS's primary functio is to expose workmanship and related defects thus reducing the removal rate (or MTBM) of the units which have masked the inherent design failure rate. The amount of logistic support cost is determined by the type of maintenance scenaric (e.g., fighter aircraft, transport, stationary ground equipment, mobile ground

$$ROI = \frac{LSCS - (AFC + TC)}{(AFC + TC)(SL - EA)} \times 100 > 33.3\%$$

WHERE:

- ROI = ANNUALIZED RETURN ON INVESTMENT
- LSCS = LOGISTIC SUPPORT COST SAVINGS
- AFC = AMORTIZED FACILITY (ENVIRONMENTAL & FUNCTIONAL TEST) COST
- TC = TEST COST (LABOR TO PERFORM ENVIRONMENTAL & FUNCTIONAL TESTS)
- SL = SERVICE LIFE OF LRU/SRU
- EA = EQUIPMENT AGE AT ESS
- 33.3% = MINIMUM ROI TO OBTAIN 3-YEAR RECOVERY OF ESS INVESTMENT

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Figure 31. Return On Investment (ROI) definition.

equipment, etc). Field operational conditions and the maintenance scenario change for different types of avionic and electronic equipment. The LRU/SRU logistic support costs are a function of the maintenance concept, i.e., whether repairs are being done at organizational, intermediate, depot, or factory levels, the discard philosophy, available personnel skill levels, etc.

6.2.1 Logistic Support Cost (LSC) Development

In order to develop the projected LSC before and after ESS as well as the expected savings due to ESS, it is necessary to utilize a methodology or model which realistically simulates the specific logistic support scenario under which the LRUs and SRUs will be maintained. Furthermore, the model must be sensitive to the changes induced by ESS, i.e., changes in MTBM/removal rate so that realistic comparative costs can be obtained.

A typical model methodology for determining projected logistic support cost is the USAF Logistic Support Cost (LSC) Model, Version 1.1, dated January 1979. This widely used model was developed for avionic systems and could be readily adapted. It uses approximately 50 input variables describing the maintenance system scenario and approximately 25 input variables describing each LRU. The typical data scenario for these inputs are provided in Appendix A. The input data for the model is obtained from sources such as Air Force AFM 66-1 maintenance data, Air Force AFLCP 173-10 "AFLC Cost and Planning Factors and AF Regulation 173-13" and "USAF Cost and Planning Factors." The key parameters driving LSC are Mean Flight Hours Between Maintenance (MFHBM) and the unit cost of the LRUs.

Table 14 illustrates the application of this model as applied to the five case history LRUs used to demonstrate the effectiveness of ESS in Sections 3, 4, and 5. The improvement due to ESS in the removal rates expressed as MFHBR and the resulting LSC savings are shown. Since these units were tested on an as new basis, the projections were evaluated over a 15 year life cycle period. The savings are particularly significant for those units having the lower MFHBR rates, while those with higher rates and lower unit costs provide marginal cost improvement.

TABLE 14. Gross direct logistic support cost savings.

				TOTAL LSC			LSC PER LRU	
LRU	AVG UNIT $	AVG MFHBR W/O ESS	AVG MFHBR W ESS	DIRECT LSC W/O ESS $M	DIRECT LSC W ESS $M	DELTA SAVINGS $M	DELTA SAVINGS $K	SAVINGS AS A % OF LRU UNIT COST
A	312,000	32	70	151.7	57.7	94.0	261.1	84
B	82 036	66	127	26.4	11.5	14.9	41.3	50
C	162,932	83	149	46.0	25.1	20.9	58.1	36
D	26,160	92	278	9.2	5.5	3.7	10.3	39
E	55,217	570	1110	3.0	1.8	1.2	4.2	8

NOTES:

- AF LSC MODEL, VERSION 1.1, JANUARY 1979; OPERATIONAL DATA IN APPENDIX A
- 1985 DOLLARS
- SERVICE LIFE: 15 YEARS
- BASED ON 15 YEAR LIFE CYCLE

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By parametrically varying the Mean Time Between Maintenance (MTBM) parameter for ratios from 1:1 to 2:1, and exercising the LSC model, logistics support cost savings as a function of MTBM (converted to removals per month) were developed and normalized as a function of the unit cost to provide a logistic support cost savings factor. These relationships are provided in Fig. 32. A service life basis of 25 years was used since this is the nominal average life of a typical weapon system.

The LSC savings factor, a function of the materials and labor cost savings, can be expressed as the number of equivalent spares that would be saved per unit LRU over the life cycle. Multiplying the factor by the unit cost would provide the dollar cost savings. For example, if an LRU had a removal rate of one per month and an improvement of 70% (MTBM improvement factor of 1.7) was estimated, then the corresponding LSC savings factor from Fig. 32 would be approximately three or three equivalent spares saved. The corresponding cost savings in dollars would be three times the unit cost per LRU, and the total cost savings for (N) LRUs would be three times the unit cost x (N) over the life of the LRU.

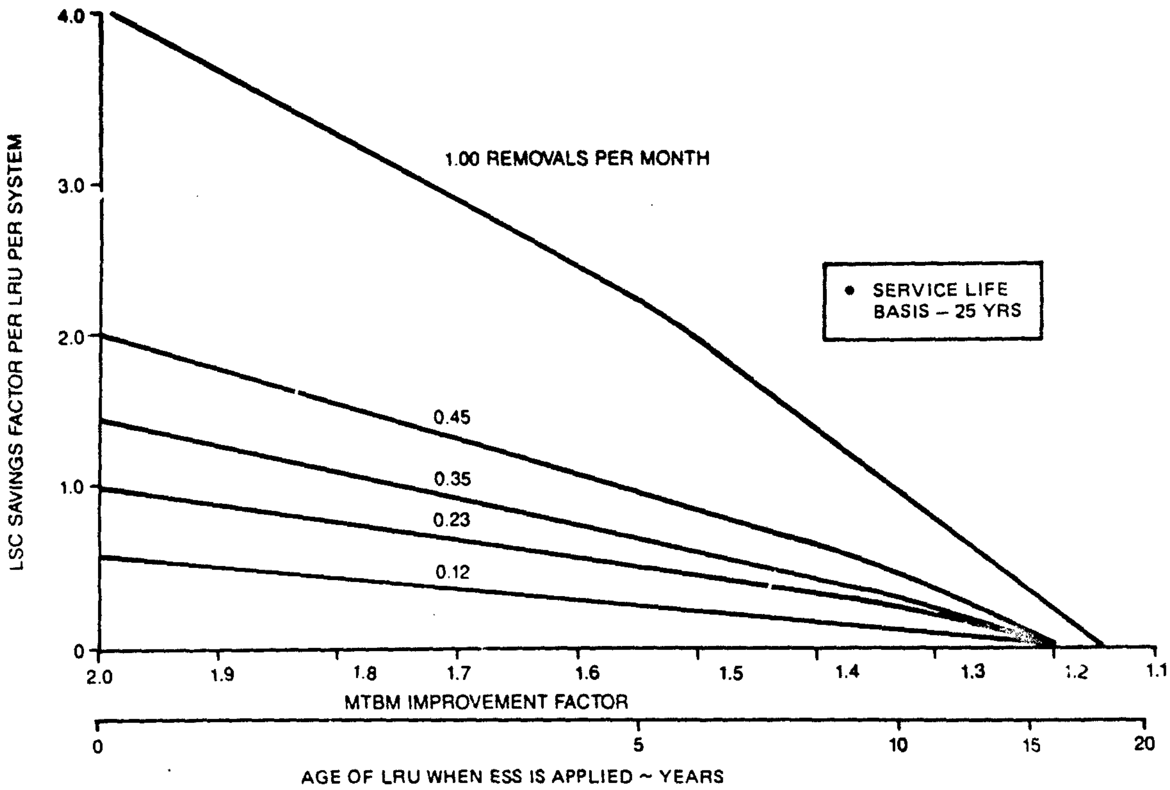

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Figure 32. Projected field ESS logistic support cost savings factor vs MTBM improvement factor.

Although these characteristics may vary as a function of the model scenario, they are fairly indicative of the orders of magnitude potential that could be achieved for planning and trade-off purposes.

6.2.2 Effect of Age on LSC Savings

Logistic support cost savings are a function of the age of the LRU/SRU at which ESS is performed, irrespective of the stress effects. The savings will be greater for the younger equipment as a result of two factors:

- If ESS were to be performed when the LRU/SRU is new in the inventory the unit will have many more years of life left during which a savings occurs
- The MTBM/removal rate will normally improve with age as operational hours are accumulated because defects will be gradually uncovered and repaired. The projected characteristic age curve developed in Section 4, Fig. 17, is superimposed on Fig. 32 to reflect the potential impact to LSCS due to the age of the LRU at the time ESS is applied.

6.3 ESS IMPLEMENTATION COSTS

ESS implementation costs consist of amortized facility costs and recurring test costs.

6.3.1 Amortized Facility (Non-Recurring) Costs

The formulation for amortized test facility cost is described in Fig. 33. Each factor in the equation must be determined by conditions existing at the facility where ESS is to be performed as well as the quantity and time schedule for LRU/SRU testing. In establishing the facility requirements costs, test duration and system loading requirements must be defined. Typical average values of the cost of environmental equipment and set-up are listed in Table 15. Cost of such equipment

$$AFC = \frac{(t) \times (N) \times (C)}{(T) \times (M) \times (K)}$$

WHERE: AFC = AMORTIZED FACILITY COST PER UNIT

t = TEST HOURS REQUIRED PER UNIT

T = NUMBER OF AVAILABLE TEST HOURS PER MONTH PER SET OF TEST EQUIPMENT

N = UNITS PER MONTH TO BE TESTED

M = TOTAL NUMBER OF UNITS TO BE TESTED

C = COST PER TEST SET-UP

K = NUMBER OF TEST PROGRAMS TO BE IMPLEMENTED

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Figure 33. Non-recurring amortized test facility cost.

TABLE 15. Typical costs of environmental equipment.

ENVIRONMENTAL EQUIPMENT	AVERAGE UNIT COST $K
TEMPERATURE CHAMBER	47
TEMPERATURE CHAMBER CONTROLS PROGRAMMER	10
VIBRATION TABLES	80
MOUNTING FIXTURE	10
RANDOM VIBRATION CONTROLLER	26
INSTALLATION COST	3
SINGLE INSTALLATION COST	176

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cannot be standardized due to the diverse competitive nature that has developed in recent years, both economically as well as technically. The costs are representative of the latest state-of-the-art test equipment supportive of conducting typical ESS testing per MIL-STD-2164(EC) and R&M 2000.

To illustrate the application, consider the following criteria:

- Number of test hours available per month (T): 480 (5 Days/wk x 24 hrs/day x 4 wks/mo)
- Test hours per unit (t) : 120
- Total Units to be tested (N) : 216
- Test equipment cost/set-up (C) : 176,000
- Number of test programs (K) : 1
- Units flow through per month (n) : 24

The amortized test facility cost per unit would then be:

$$AFC = \frac{(t)\ (n)\ (C)}{(T)\ (N)\ (K)} = \frac{120\ (24)\ (176{,}000)}{(480)\ (216)\ (1)}$$

AFC = \$4890/unit

Therefore testing conducted under the above conditions is amortized at \$4890 per unit. Factors dropping the cost would include:

- Reducing the test duration; if testing were to be reduced to 40 hrs/unit, the cost would be reduced to \$1630 per unit. Figure 34 provides graphic illustration of test duration versus the AFC effects described in the illustration
- Reducing the number of test set-ups to handle the flows would also be a factor in reducing the cost impact. However, planning plays a major roll when you consider that vibration equipment would be required only approximately 5 minutes out of every 40 hours of testing (8%); this results in requiring one vibration system for every five to 10 temperature chambers. Since vibration equipment cost represents 65% of the total test equipment cost, the amortized cost per facility set-up could be significantly reduced for high density flowthroughs.

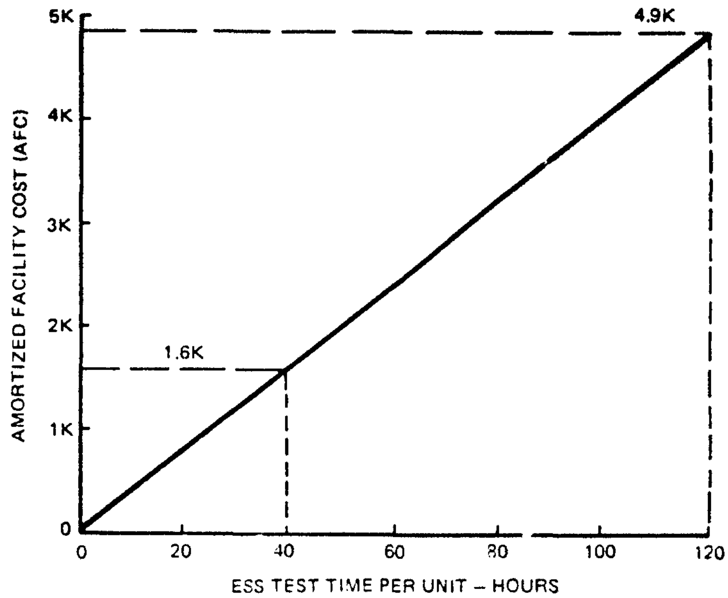

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Figure 34. Amortized facility cost per unit as a function of ESS test duration.

6.3.2 Cost of Testing

Recurring costs or costs to physically perform the testing include:

- Cost of labor to perform tests
- Cost of labor for electrical functional testing of LRUs and SRUs
- Cost of spares to support repair
- Cost of repairs for failures encountered during test
- Cost of shipping LRUs and SRUs to and from the depot.

Most of these costs can be developed as a function of the logistic support cost for the unit under test. The testing will make in effect, unexpected logistic and repair demands, not necessarily planned for as part of the normal maintenance rate of the equipment, as well as present demands for additional special support equipment, as may be needed to perform functional verification of the equipment under test. The cost of labor to perform ESS is a function of the test time and labor rate of personnel required.

Figure 35 provides a cost algorithm for defining the Direct Test Cost (DTC). The cost is simply the manpower and supply necessary to detect, fault isolate, and repair defects or failures encountered during the testing.

$$\text{DIRECT TEST COST (DTC)} = \left(\frac{\text{LOGISTIC SUPPORT COST (LSC)}}{\text{TOTAL NUMBER OF REPAIRS (R)}}\right) \cdot \left(\begin{array}{l}\text{UNIT PROCESS}\\ \text{AVERAGE } (\mu)\\ \text{(EXPECTED NO. OF DEFECTS/UNIT)}\end{array}\right)$$

WHERE: LOGISTICS SUPPORT COST (LSC) = LOGISTIC SUPPORT COST FOR LRU/SRU AS DETERMINED FROM LSC MODELS

$$\text{TOTAL NUMBER OF REPAIRS/REMOVALS (R) PER LRU/SRU} = \frac{\text{SYSTEM OPERATING TIME PER YEAR}}{\text{MTBM}} \times \text{LRU/SRU SERVICE LIFE}$$

$$\text{UNIT PROCESS AVERAGE } (\mu) = \frac{\text{SYSTEM OPERATING TIME PER YEAR}}{\text{MTBM}} \times \frac{1}{N \cdot K}$$

- N = NUMBER OF SYSTEMS OPERATING
- K = NUMBER OF LRU/SRUs PER SYSTEM

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Figure 35. Direct test cost algorithim for ESS.

The cost of labor and materials for repairs during ESS can be calculated using a variety of methods. One method would be to find an average cost per repair based upon historical experience with the LRU/SRU. Another method (Fig. 35) uses an LSC model to determine the total logistic support cost over the life of the LRU/SRU and the total number of expected repairs, and dividing these to arrive at a cost per repair. The cost per repair averages approximately 2.3% based on historical experience (Ref 8) of the spares unit acquisition cost of the LRU/SRU.

The expected number of defects or repairs to be encountered during the test are a function of the number of removals per unit (μ) or process average, as defined in Section 4. These would be the normal number of defects encountered, given that ESS testing is stress dependent and accelerates the defects as they exist, not as they occur in time dependent scenarios.

Using the average cost per repair of 2.3% of the spares unit acquisition cost, Fig. 36 was developed which shows the repair cost during ESS versus the spares unit acquisition cost for various process averages (μ) values of expected defect repairs.

It should be noted that spares unit acquisition cost is the basis of this calculation because it is the cost at which spare LRUs/SRUs are purchased and it is generally proportional to the complexity of the units, its MTBM, and to the cost of maintenance of the unit.

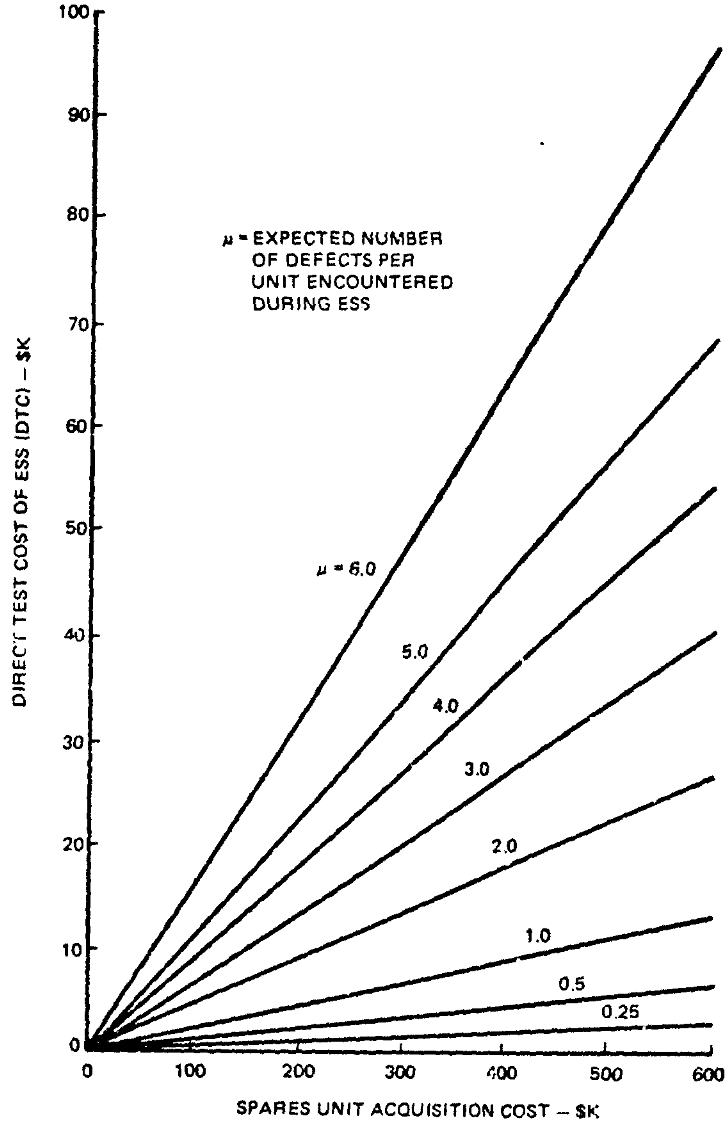

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Figure 36. Direct test cost as a function of unit acquisition cost & process average (μ)

6.4 COST BENEFIT ANALYSIS

To assess the cost benefit effects of applying ESS in a field environment, the procedure defined in the flow diagram of Fig. 37 was implemented. Field data development was based on an EF-111A aircraft scenario, and a select number of LRUs were used to demonstrate the process and trade-off techniques. The selected LRUs are as listed in Table 16 which includes pertinent statistical data as applied in the analyses. Weapon system deployment and operational statistics are provided, with

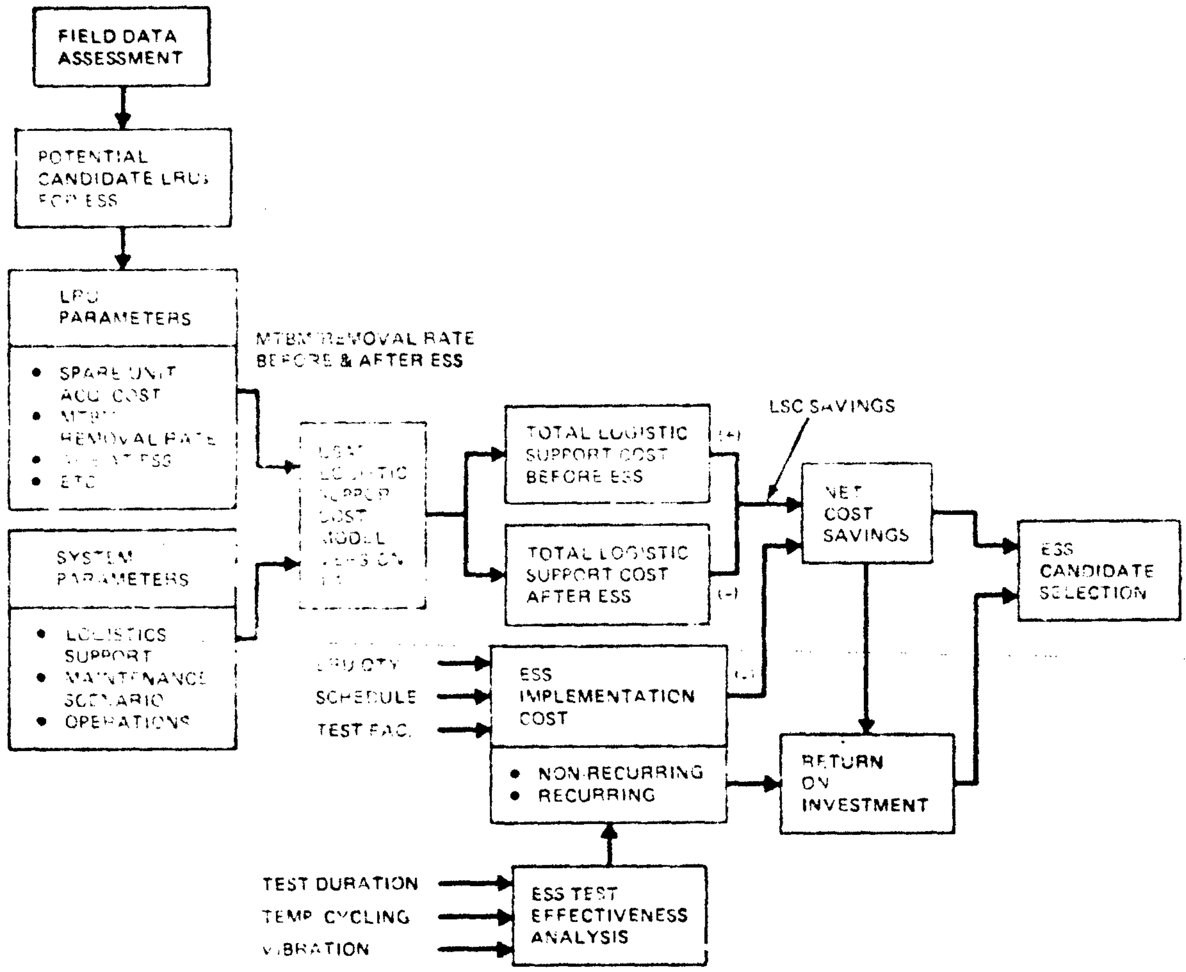

Figure 37. Procedure for economic analysis.

appropriate assumptions, in Appendix A as well as relevant LRU data as developed from AF/D056 Data System for the reporting period from July 1984 through June 1986.

6.4.1 Logistic Support Cost Savings (LSCS) Effects

Field data assessment was used to determine potential candidate LRUs for ESS using the methods described in Sections 3 through 5. The LRU unit rank by removal is provided in Appendix B. Of the six equipments selected, five were pulled from the top 25 ranked for high removals for the reporting period (including number 1 ranked MBE unit), and a sixth just below the top 25 (the DDD ranked number 31). The parameters of the LRUs were inserted into the LSC model for obtaining downstream projected logistic support costs. These are provided in Table

TABLE 16. LRU selection profiles.

LRU	SPECIFIED MTBF	OPERATIONAL MFHBR	NUMBER OF UNITS REPORTING (N)	UNIT COST $K	PROCESS AVG PER UNIT (μ)	SERVICE LIFE YEARS	HIGH RMVL RATE RAN
EXCITER (MBE) (WUC 76ZMO)	500	31	144	487	3.0	25	1
RF CALIBRATOR (RFC) (WUC 76ZPJ)	1500	67	36	174	4.2	25	7
RADAR IR INDICATOR (RIRI) (WUC 73BRO)	1165	85	36	302	3.2	25	11
COMPUTER SYNC UNIT (CSU) (WUC 76Y20)	502	88	36	444	3.3	25	12
SIGNAL DATA CONVERTER (SDC) (WUC 76Y20)	848	133	36	401	1.5	25	17
DIGITAL DATA DISPLAY (DDD) (WUC 76Y10)	853	257	36	116	1.1	25	31

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A-4 of Appendix A. The MFHBR removal rates before and after ESS were used i the LSC model to generate the LSC values before ESS, and then after as a functio of the improvement, based on an initial maximum improvement assumed at 2:1. Th rates were then parametrically reduced as a function of equipment age at which it assumed the LRU is being tested. This was done using the LSCS generic curve developed in Fig. 32. The LSC savings effects developed are as shown in Table 1 The assumed ages of the LRUs at the time of ESS were varied to assess the potent parametric relationship that could develop. Overlaying the removal rates (in tern of removals per month) onto the generic LSCS curves in Fig. 32 provides the improvement factor effects that can be derived. The results are graphically provided in Fig. 38. It can be seen irrespective of any other cost effect that ma further reduce the LSCS due to the test implementation costs, that the smaller th change in the removal rate the smaller the logistic support cost savings. The MBI the highest ranked item and the DDD, the lowest ranked item, set the boundarie with all other units falling in the midrange.

6.4.2 Implementation Cost Effects

ESS Implementation Costs were developed as a function of the ESS test durati extremes:

- Assuming implementation of MIL-STD-2164(EC), which is 40 hours of burn-in

TABLE 17. Logistic support cost savings effects as a function of changes in removal rates (MFHBR).

LRU	UNIT COST $	AGE AT ESS (YRS)	MFHBR W/O ESS	MFHBR W ESS	LSC* SAVINGS FACTOR	LSC SAVINGS PER UNIT $
MBE	487000	0	30	60	4	1948000
		1	30	57	3.6	1753200
		3	30	52	2.9	1412300
		5	30	46	2.2	1071400
		10	30	40	1	487000
		15	30	37	0.3	146100
RFC	174000	0	67	134	2	348000
		1	67	128	1.8	313200
		3	67	116	1.6	278400
		5	67	104	1	174000
		10	67	90	0.5	87000
		15	67	82	0.1	17400
RIRI	302000	0	85	170	1.4	422800
		1	85	162	1.3	392600
		3	85	147	1	302000
		5	85	131	0.7	211400
		10	85	113	0.3	90600
		15	85	104	0.1	30200
CSU	444000	0	88	176	1.4	621600
		1	88	168	1.3	577200
		3	88	152	1	444000
		5	88	136	0.7	310800
		10	88	117	0.3	133200
		15	88	108	0.1	44400
SDC	401000	0	129	258	1	401000
		1	129	246	0.9	360900
		3	129	223	0.7	280700
		5	129	99	0.5	200500
		10	129	[illegible]	0.3	120300
		15	129	143	0	0
DDD	116000	0	257	514	0.6	69600
		1	257	491	0.5	58000
		3	257	445	0.4	46400
		5	257	396	0.3	34800
		10	257	342	0.1	11600
		15	257	285	0	0

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*OBTAINED FROM FIG. 32 (SUBSECTION 6.2.1)

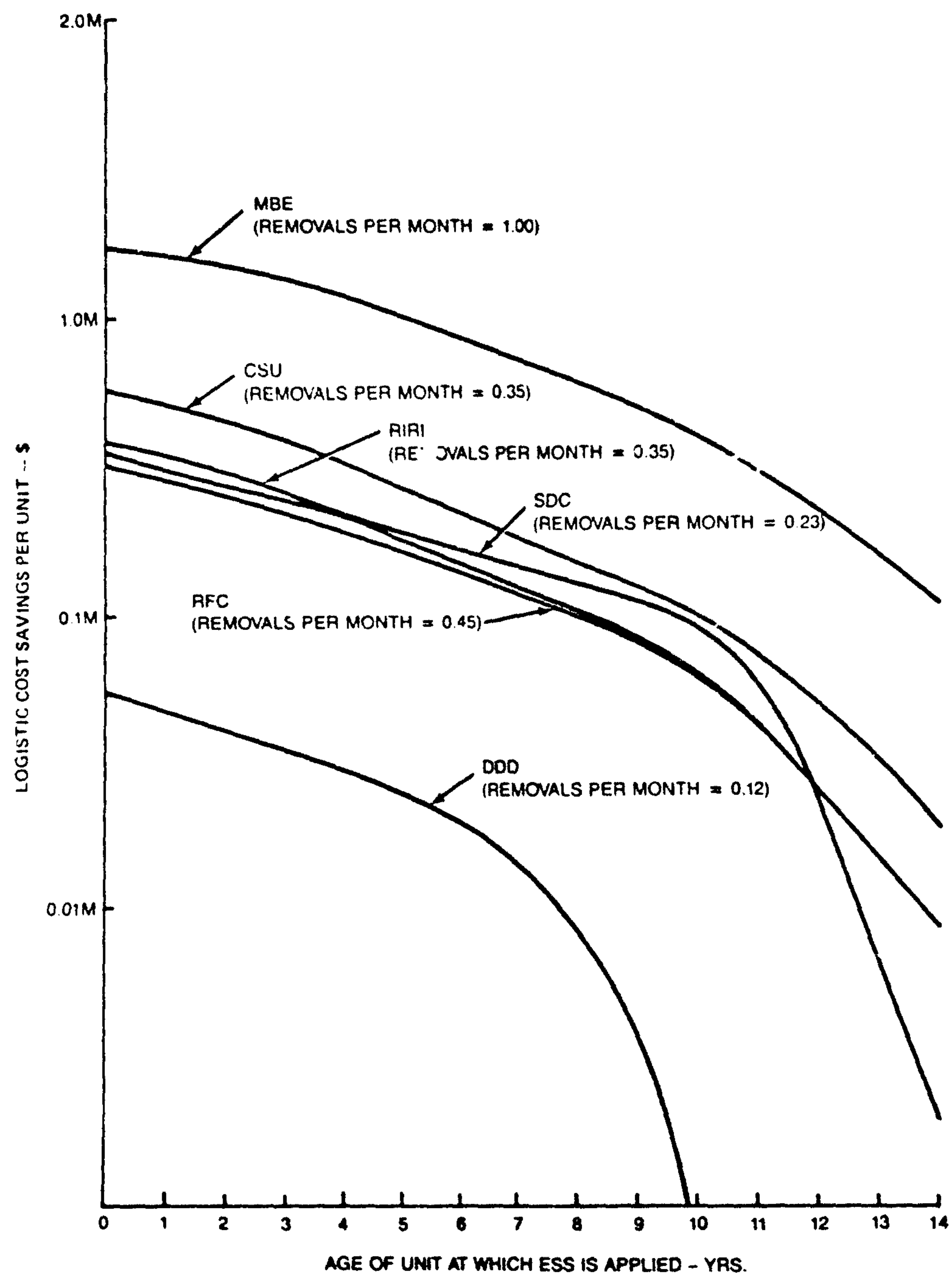

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Figure 38. Logistics cost saving per unit vs equipment age at which ESS is applied.

and then 40 hours failure free in an 80 hour window for a potential maximum duration of 120 hours of testing

- Implementation of recommended duration reduction for field inventoried equipment of 40 hours, without failure free as discussed in Section 5.

The ESS implementation costs were developed using the algorithms for both non-recurring and recurring costs in Subsection 6.3. The cost developed for each LRU is provided in Table 18.

TABLE 18. Development of ESS implementation cost per unit tested.

LRU	TOTAL* LSC BEFORE ESS $M	*TOTAL REPAIRS PER LIFECYCLE	COST PER REPAIR $K	PROCESS AVG (μ) REMVLS/ UNIT	††† REPAIR COST DURING ESS $K	**TEST FACILITY LABOR $K	$ AMORT. FACILITY COST/UNIT	TEST IMPLEMENT COST $K
MBE	143.2	13500	10.6	3.0	31.8	6	3240	41.0
RFC	24.3	6018	4.0	4.2	16.0	6	3240	25.2
RIRI	32.4	4765	6.8	3.2	20.4	6	3240	29.6
CSU	45.7	4765	9.6	3.3	28.8	6	3240	38.0
SDC	28.0	3140	8.9	1.5	17.8	6	3240	27.0
DDD	4.9	1576	3.1	1.1	3.1	6	3240	12.3

*OBTAINED FROM LSC MODEL

**TEST LABOR COST, ASSUMES TWO PEOPLE TO MONITOR TEST EQUIPMENT AT 120 HRS PER TEST AT $25/HR

†††OBTAINED FROM FIG. 36 (SUBSECTION 6.3.2) FOR PROCESS AVG (μ)

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Amortized facility costs were developed assuming the flow rate of 324 units, with testing of all units to be completed within a year or 27 units per month. The available test hours per month were assumed at 480. This results in non-recurring AFC of $3240/unit for the 120 hour test and $1080/unit for the 40 hour test. A comparison of the ESS implementation cost per unit for the 120 hour and 40 hour test durations indicates that the ESS implementation cost is averaging between 9% and 7% of the unit cost noted in Table 19. The only costs that are actually affected by the

TABLE 19. ESS implementation cost as a function of unit cost.

EQUIPMENT	$K UNIT COST	ESS IMPLEMENTATION COST $K		% UNIT COST	
		120 HR	40 HR	120 HR	40 HR
MBE	[illegible]17	41	34.8	8%	7%
RFC	74	25.2	19.1	14%	11%
RIRI	302	29.6	23.5	10%	8%
CSU	444	38	31.9	9%	7%
SDC	401	27	20.9	7%	5%
DDD	116	12.3	6.2	11%	5%
			AVG	9%	7%

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reduced test duration are the AFC and the test facility labor cost. Repair costs will be unaffected. As noted for the MBE in Table 19, there is little cost effect due to test duration (8% for 120 hours compared to 7% for 40 hours). This is because the repair yield will be high in either event. For the DDD unit, the yield will be low and the test duration will now have an effect (more than one half the cost, [illegible]% for 120 hours compared to 5% for 40 hours).

The resulting test implementation costs developed (cost for 120 hour testing was used) were then subtracted from the LSCS developed in Table 17, and the net cost savings and ROI were computed to develop Table 20. The cost savings rank provides an overview indication of candidate equipments to be tested if you had varying conditions of age and improvement factors to contend with in the selection process. The MBE, by virtue of its frequency, eclipses almost all other candidates for all age and rate improvement categories.

6.4.3 Return On Investment (ROI)

The annualized ROI was computed in accordance with the formula in Fig. 31 and these results are shown in the final column of Table 20 for each LRU and ESS age. The listings provide an indication of the combinations that will have a 33% ROI or better and are the most likely candidates. Significant notes include:

- Equipment whose age exceeds 10 years at a time of evaluation offers little in the way of economic benefit
- Contributors beyond the top 25 are not cost effective as noted by the DDD unit, which was ranked 31 and could not break 33% under any condition.

Figure 39 (1 through 6) is developed to assess the variation in the ROI as a function of the efficiency of the test program, that is, the percentage of defects that are reduced and the test duration. The graphic comparisons are for defect yield rates of 100% (Fig. 39 (1 and 2)), 50% (Fig. 39 (2 and 3)), and 25% (Fig. 39 (5 and 6)) considering the test durations of 120 or 40 hours as well as the age at the time the LRU is tested. In both test duration categories, as the potential gain in removal rate is reduced, the number of economically viable units significantly reduces (ROI drops below 33%). Reducing the number of units to be tested while retaining a high potential for defect reduction, such as the case with selecting bad actors, would provide the best economical combination (together with the reduced test time) possible, as illustrated by Fig. 39 (1).

TABLE 20. ESS projected cost savings & return on investment.

LRU	UNIT COST $	AGE AT ESS (YRS)	MFHBR W/O ESS	MFHBR W ESS	LSC* SAVINGS FACTOR	LSC SAVINGS PER UNIT $	ESS** IMPLEMENT COST $	NET SAVINGS PER UNIT $	COST SAVINGS RANK	ANNUAL RETURN ON INVESTM'T %
MBE	487000	0	30	60	4	1948000	41000	1907000	1	186
		1	30	57	3.6	1753200		1712200	2	174
		3	30	52	2.9	1412300		1371300	3	152
		5	30	46	2.2	1071400		1030400	4	125
		10	30	40	1	487000		446000	7	73
		15	30	37	0.3	146100		105100	22	26
RFC	174000	0	67	134	2	384000	25200	322800	13	51
		1	67	128	1.8	313200		288000	14	48
		3	67	116	1.6	278400		253200	16	46
		5	67	104	1	174000		148800	21	30
		10	67	90	0.5	87000		61800	25	16
		15	67	82	0.1	17400		-7800	34	-3
RIRI	302000	0	85	170	1.4	422800	29600	393200	9	53
		1	85	162	1.3	392600		363000	11	51
		3	85	147	1	302000		272400	16	42
		5	85	131	0.7	311400		181800	19	31
		10	85	113	0.3	90600		61000	26	14
		15	85	104	0.1	30200		600	32	0
CSU	444000	0	88	176	1.4	621600	38000	583600	5	61
		1	88	168	1.3	577200		539200	6	59
		3	88	152	1	444000		406000	8	49
		5	88	136	0.7	310800		272800	15	36
		10	88	117	0.3	133200		95200	23	17
		15	88	108	0.1	44400		6400	31	2
SDC	401000	0	129	258	1	401000	27000	374000	10	55
		1	129	246	0.9	360900		333900	12	52
		3	129	223	0.7	280700		253700	17	43
		5	129	199	0.5	200500		173500	20	32
		10	129	172	0.3	120300		93300	24	23
		15	129	143	0	0		-27000	36	-10
DOD	116000	0	257	514	0.6	96900	12300	57300	27	19
		1	257	491	0.5	58000		45700	28	16
		3	257	445	0.4	46400		34100	29	13
		5	257	396	0.3	34800		22500	30	9
		10	257	342	0.1	11680		-700	33	0
		15	257	285	0	0		-12300	35	-10

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*OBTAINED FROM FIG. 32 (SUBSECTION 6.2.1)

**OBTAINED FROM TABLE 18 (SUBSECTION 6.4.2)

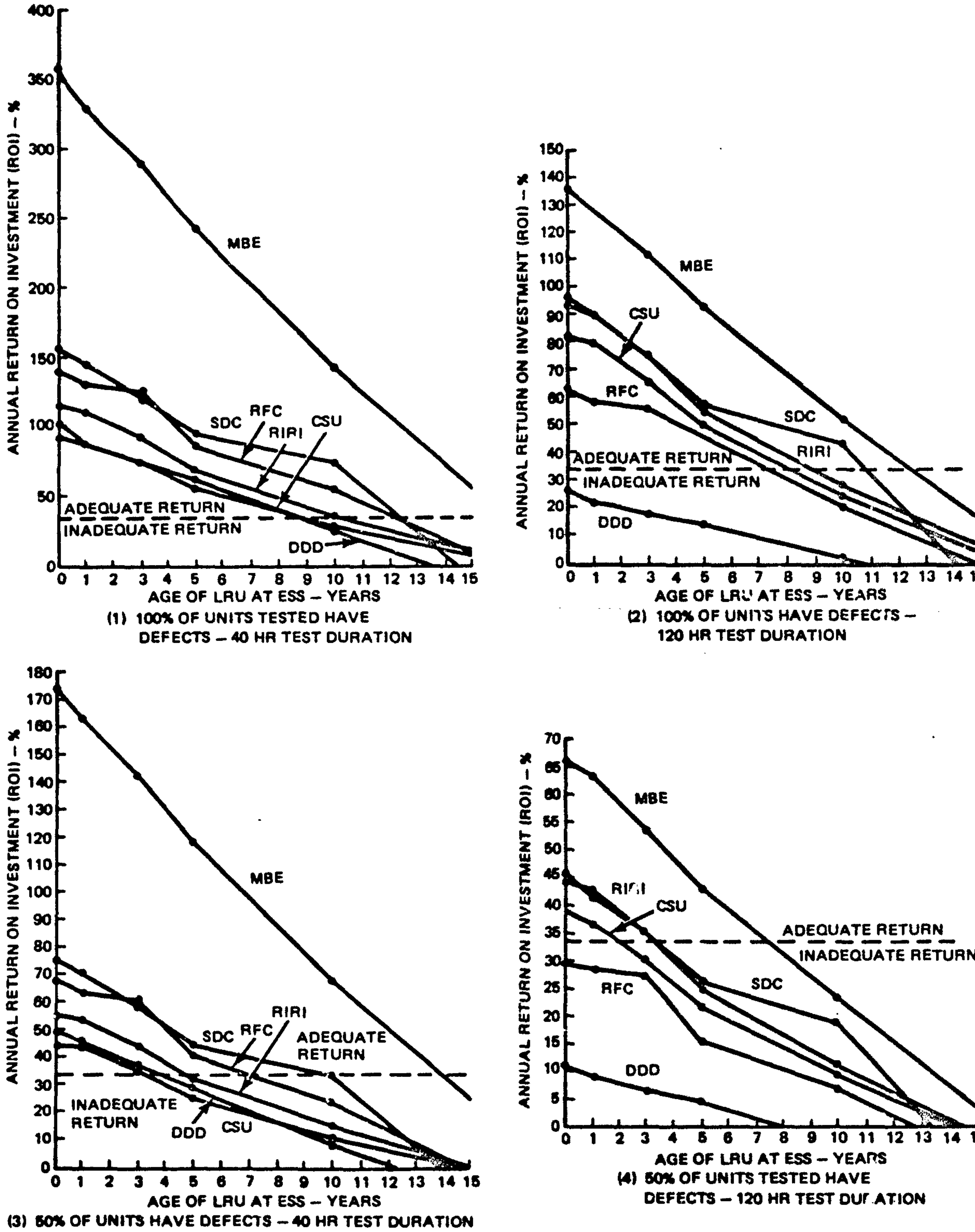

Figure 39. ROI effects as a function of ESS test efficiency (sheet 1 of 2).

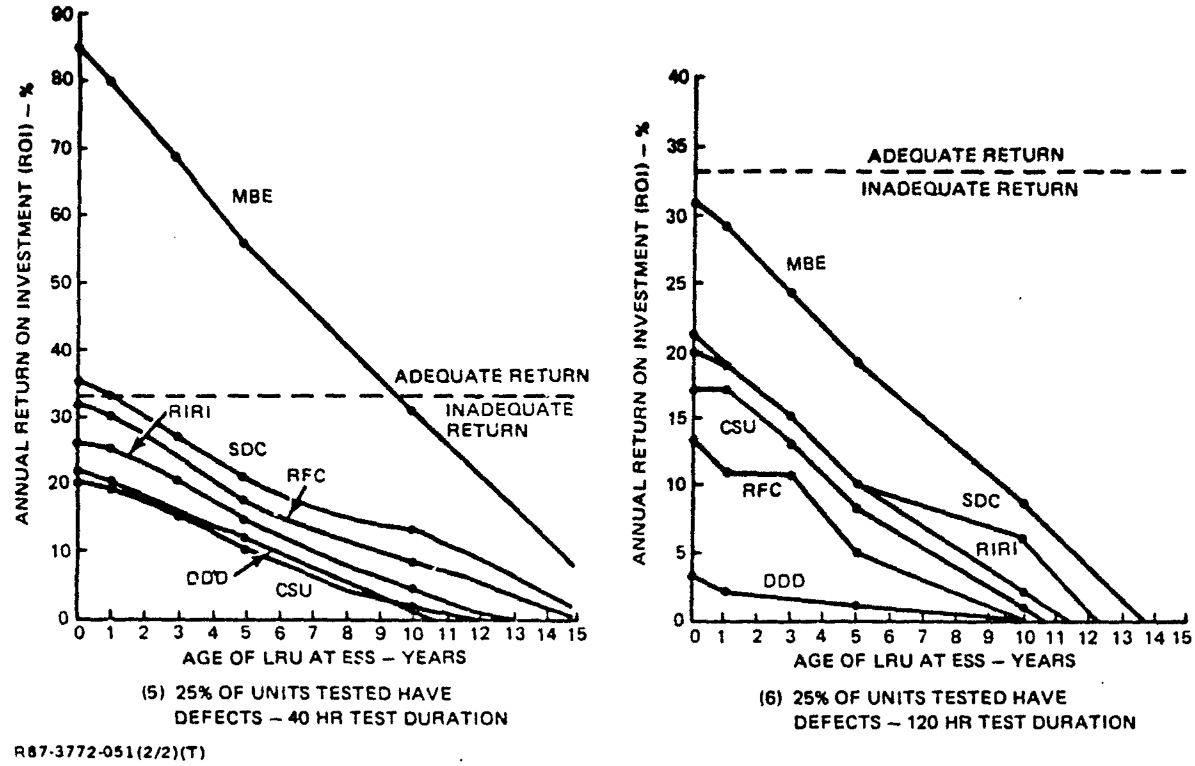

Figure 39. ROI effects as a function of ESS test efficiency (sheet 2 of 2).

Similarly, in testing SRUs (which represent only a fraction of the potential defects rate), unless they have a significant contribution of the LRU's defect population, the economic potential (as can be derived from the removal rate improvement) is not justifiable, and the potential is practically non-existent as the test duration increases to 120 hours, as illustrated by Fig. 39(6).

6.5 COST BENEFIT CONCLUSIONS

Based on the analyses conducted, it has been shown that:

- Equipment age should not be greater than 10 years at the time ESS is implemented, ROI falls well below 33% unless the LRU is a significant contributor to the weapon system removal rate
- ROI of 33% is a good indication of potential cost benefit that can be realized as a result of field ESS
- Unless unit under consideration is a high removal rate contributor (top 25 or better) cost benefit is well below expectation
- Reduced test duration (elimination of failure free categorization) offers opportunity to test more for less

- High bad actor effectiveness selection would be the optimal cost benefit effect that could be achieved (fewest units tested, high potential defect yield)
- Lower level of assembly testing should be able to demonstrate significant improvement in removal rate, nominally greater than 25% to insure effective pay-off of field ESS
- ESS test implementation costs based on repair costs as a function of logistic support costs per repair, could average between 7% and 9% of unit cost, which includes any amortized facility costs. This cost covers additional sparing and support equipment requirements resulting from the testing and repair of units selected.

7 - CONCLUSIONS & RECOMMENDATIONS

7.1 FIELD ASSESSMENT

- Comparative analysis of established case histories of electronic LRUs has demonstrated, via field history performance, effective improvement in total removal rates attributable to ESS. This is concluded by:
  - Reduction of overall removal rates, on the order of 2:1 across the board for ESS populations
  - Significant stability of removal rate frequencies and frequency levels for ESS populations as compared to more widely dispersed rates for non-ESS populations
  - Improved removals per unit by LRU serial number.

7.2 DATA REDUCTION

- The grouping of data in terms of Type 1 (performance), Type 2 (maintenance induced), and Type 6 (false alarm) maintenance actions provides some intuitive attributes that can identify potential latent (workmanship) defects, as compared to inherent (design) defects. This grouping consists of:
  - Latent characteristic actions:
    - Type 1 maintenance actions resulting in repair without parts
    - Type 2 maintenance reduced actions
    - Type 6 false alarms (or cannot duplicate)
  - Inherent characteristic actions:
    - Type 1 maintenance actions resulting in repair with parts
    - NRTS (Not Repaired This Station) - hardware returned to depot for further disposition
- Assessment of bad actor serialized LRUs provided significant insight into the behavior pattern of these actions. As noted in Table 21, the percent in removal rate gain affected by the bad actor selection, shows Type 6 actions gaining at a rate of about 2:1 in contrast to either of the Type 1 conditions (with parts or without parts). This is highly indicative of the elimination of intermittent defects that tend to create false alarms. Type classification and the organization of maintenance actions in the data reduction process,

TABLE 21. Percent gain distribution in removal rate as function of bad actor removal.

EQUIPMENT	INHERENT TYPE 1 WITH PARTS %	LATENT TYPE 1 W/O PARTS %	TYPE 2 & TYPE 6 %
A	13%	35%	45%
B	21%	10%	49%
C	20%	7%	43%
D	17%	26%	20%
E	11%	20%	62%
*WEIGHTED AVERAGE	16%	21%	44%

WEIGHTED AVERAGE AS A FUNCTION OF REMOVAL RATE

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therefore, do offer potential for assessing ESS effects from a field reporting point of view. But once again, these can only support circumstantial conclusions, since inherent and latent characteristics are extremely difficult to quantify without supporting failure analysis data.

7.3 LEVEL OF ASSEMBLY SENSITIVITY

- In the field scenario the LRU provides the collection point for quality related problems. It is the focal point of all field maintenance reporting and provides reasonable traceability to establish quality characteristics, including measurable removal rates and individual unit traceability by serial number
- The SRUs and other lower levels of assembly offer no traceability and require accountability through the cognizant ALC. Since the ALC is not the assembly point of the LRU, there is no process control that can be affected through the screening of the lower levels of assembly. Further, SRU and lower level component screens are highly sensitive to the contribution the level hardware is actually making to the LRU removal rate. Selection at lower levels for field screening must be carefully assessed to establish that the screen will have an impact on the LRU on a per repair basis. This is reflected by the fact that, for the case histories studied, neither SRUs, lower levels of assembly, nor piece parts were screened other than as required per the component specifications, and the LRU ESS population at their current repair rates have not shown any degradation over a period of five years.

7.4 SELECTION CRITERIA

- High removal contributor ranks provide the prioritization of equipment and LRUs to initiate the process of picking candidate hardware for screening. This is made possible by the fact that the total number of equipment removals from a weapon system is nominally contributed by a relatively small percentage of the total population of electronic equipment making up the system. Unless the candidate LRU is a high removal contributor initially, the effect field ESS can have on the aggregate removal rate is minimal
- Comparisons of removal rates (MTBR) to predicted or specified reliabilities (MTBF) provide some insight to potential candidates in that the latent type defects will suppress the true failure rate. This is particularly significant for small population systems, e.g., ground radars, ground test equipment, etc where processes such as bad selection is not feasible. The discrimination ratio of $\frac{MTBF}{MTBR} > 1$ provides the indication of potential candidate selection. The greater the magnitude, the greater the possibilities.

7.5 BAD ACTOR SELECTION

- Bad actor selection provides a process for selecting a small number of LRUs from the high contributor population, identifiable by serial number, which provide the highest percentage of ESS sensitive defectives. It is concluded that this approach warrants further investigation, since it identifies specific units having frequencies higher than the operational norms. This is particularly significant when you consider that the pulling LRUs from the field for testing is highly undesirable, from a field readiness and equipment availability point of view. It is recommended that pilot programs be established to access the feasibility and effectiveness of such a program.

7.6 EQUIPMENT AGE

- Equipment age and growth effects cannot be clearly quantified. Extrapolation and averaging of growth experience curves of the five case histories tend to indicate that LRUs tested beyond 10 years of age offer little improvement benefit as a result of screening. This cannot be supported by the study's case history ESS population since all equipments tested were new and not field deployed. The nature of age effects can only be determined as a function of experience factors which up to this time have not been

available. This is supported by existing army tailoring studies (Ref 9) which indicate that a successful ESS program can be implemented on overhauled units of between 15 and 25 years in service.

7.7 GENERIC ESS

- The case study LRUs were all generic ESS tested. In all cases, as concluded from the field performance assessment, results showed on the order of 2:1 improvement over the non-ESS counterparts. Since the field ESS implementation program is planned for field deployed equipment, normally repaired at a depot, it is recommended that a generic ESS profile as typically defind by MIL-STD-2164 (EC) be used. This will simplify ESS test operations, reduce ESS test equipment set-up costs and minimize ESS training requirements. To minimize the potential for stress over exposure, particularly to older equipment, it is recommended that the failure free portion of the testing be reduced, as long as each ESS defect encountered is repaired when it occurs. It is expected that during a full functional 40 hours of cycling there will be a justifiable amount of failure-free time to validate the repair
- SRU screens should be limited to spares and those items which have experienced higher failure rates in the field. The optimum environmental test in these cases is a non-operating thermal shock defined in the Field ESS Implementation Guidelines in Appendix C
- Tailoring should be considered in those cases where the probability exists that the equipment may not have been designed to function in a generically defined random vibration or rapid thermal cycling environment. Techniques as defined in Subsection 5.6 should be considered to minimize the potential problem for the equipment when generic ESS levels are applied.

7.8 ESS ECONOMICS

- The economics of ESS based on ROI (nominally 33-1/3%) are effectively achieved most consistently by testing a minimum number of units that can be selected to provide a maximum defective yield. Bad actor selection offers the best opportunity to achieve these goals. To maximize the cost benefit:
  - Units selected should be high removal rate contributors. This will maximize the logistics support cost savings

- Reduced test durations (by eliminating failure free) reduce test implementation cost by minimizing test facility loading
- Lower levels of assembly testing should demonstrate significant improvement potential in removal rate, nominally greater than 25% to ensure effective ROI pay-off
- The combination of equipment service life at time of test and rate improvement should be such to insure at least 33% ROI.

7.9 FIELD ESS IMPLEMENTATION GUIDELINE

- The guideline as provided in Appendix C defines, as a minimum, the methodology to develop an economically viable program by implementing technically sound techniques. Figure 40 provides the recommended implementation task flow requirements. The ESS selection program recommended is divided into four major areas:

  (1) Equipment Selection - based on existing AFD056 and MODAS databases and supporting ALC data, and establishes equipment population and maintenance rate histories sensitive to ESS

  (2) Selection Criteria - establishes selection means to minimize the quantity and quality of the equipment selected for testing

  (3) Test Profile Development - obtain equipment's environmental qualification and operational capabilities, and apply generic temperature and vibration levels and durations, which include test tailoring practices and considerations

  (4) Economic Selection - conduct cost studies to optimize facility, test equipment, manhours, and test requirements to accurately assess all costs to determine if an ROI savings is obtainable.

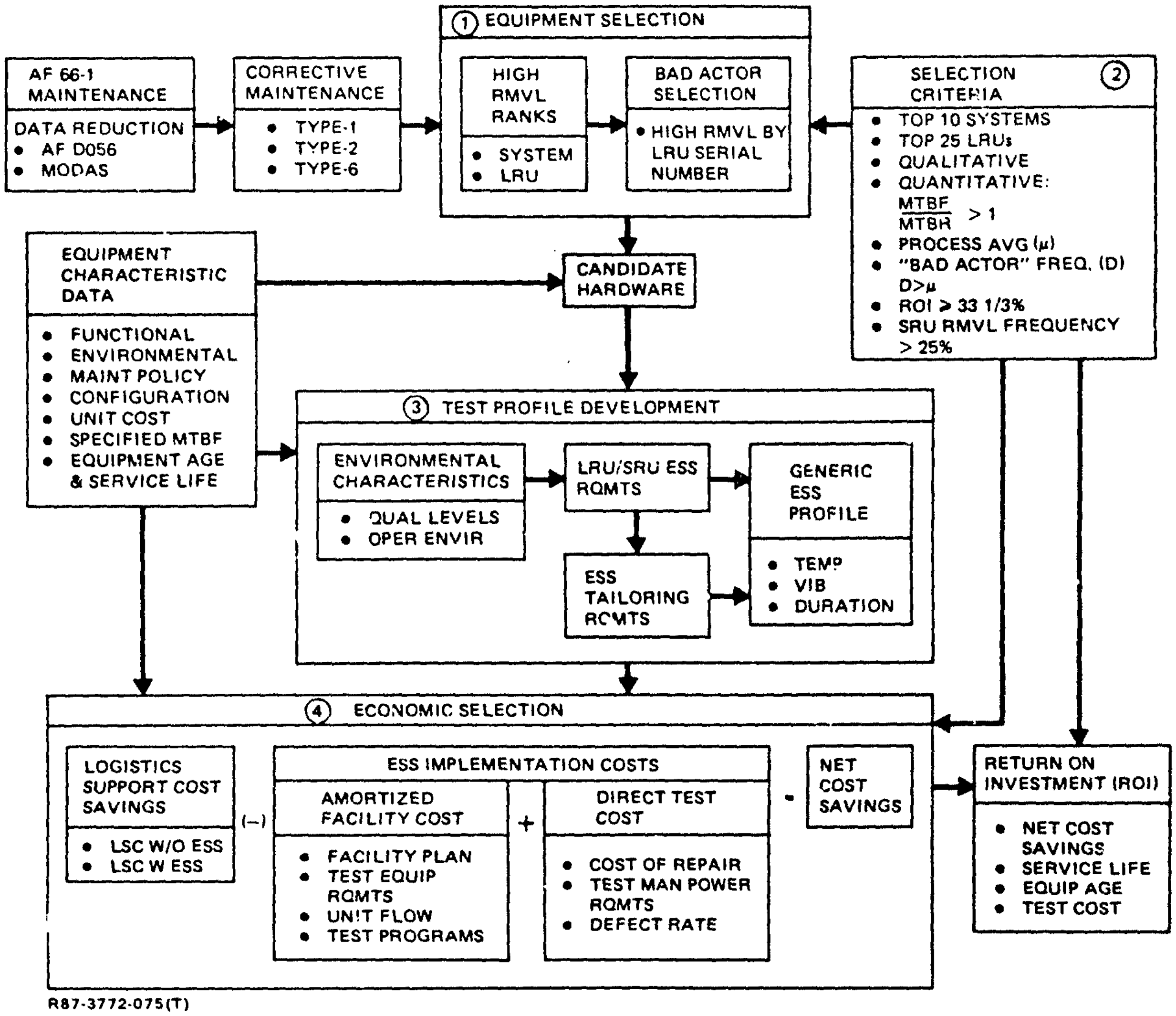

Figure 40. Field ESS implementation program task flow.

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MIL-STD-109 Quality Assurance Terms and Definitions

MIL-STD-721 Definition of Terms for Reliability and Maintainability

MIL-STD-1235 Single and Multi-level Continuous Sampling Procedures and Tables for Inspection By Attribute.

Handbooks

MIL-HDBK-217 Reliability Prediction of Electronic Equipment

DOD-HDBK-344 (USAF) Environmental Stress Screening of Electronic Equipment

Specifications

MIL-M-38769 Work Unit Code Construction and Application

Publications

Air Force

LSC Model Version 1.1 Logistic Support Cost Model User's Handbook

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AFLC R&M 2000 Environmental Stress Screening General Guidelines and Minimum Requirements, Dec 85

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10 - DEFIN .ONS & ACRONYMS

10.1 DEFINITIONS APPLICABLE TO THIS REPORT

AFD056 - Output process data tapes and reports compiled in accordance with D056 Data System directive for reporting AF66-1 Maintenance Data Collection.

Army UMSDC - Unscheduled Maintenance Sample Data Collection System, output process data tapes and reports compiled in accordance with Army regulation TR-216.

Attributes - A characteristic or property which is appraised in terms of whether it does or does not exist (go or no go), with respect to a given requirement.

Bad Actor or Loser Box - Units of product which have a frequency of removals greater than the norm or process average.

Consumable - An item of material used up beyond recovery in the use for which it was designed or intended.

Defect - Any non-conformance of the unit of product with specified requirements.

Defective - A unit of product which contains one or more defects.

Discrimination Ratio (DR) - The measure of steepness between specified MTBF(s) and MTBR to discriminate between high and low product defective potential. Numerically

- $\frac{MTBF(s)}{MTBR} \leq 1$; low potential
- $\frac{MTBF(s)}{MTBR} > 1$; high potential

Environmental Stress Screening (ESS) - A series of environmental tests conducted to disclose weak parts, workmanship defects and manufacturing process anomalies.

ESS Test Profile - The sequence and duration of stress environments under which item is to be subjected.

Failure Free Time - A contiguous period of time (in terms of environmental cycles) during which an item is to operate without the occurrence of a failure while under environmental stress.

Failure Rate - Reciprocal of MTBF.

Field ESS - ESS performed by a cognizant equipment ALC, in lieu of manufacturer at the manufacturer's facility.

Inherent Defect - A failure or defect that is a function of the intended design application of the item, when operated in its intended operational and logistic support environment.

Latent Defect - A process induced (manufacturing, quality, maintenance) weakness, not detected by ordinary means, which will either be precipitated by ESS screening conditions or eventually fail in its intended use environment.

Line Replaceable Unit (LRU) - A unit normally removed and replaced as a single item which consists of assemblies (SRUs), accessories, and components that collectively perform a specific functional operation.

Maintenance Action - An element of a maintenance event. One or more tasks (e.g., removal, fault detection, fault isolation, repair and inspection) necessary to retain an item in, or restore to, a specific condition.

Maintenance Event - One or more maintenance action required to effect corrective maintenance due to any type of failure, or malfunction, false alarm. Categerization of maintenance events based on the D056 Air Force definition are as follows:

- Type 1 - this code indicates that the item can no longer meet the minimum specified performance requirements due to its own internal failure pattern.
- Type 2 - this code indicates that the item can no longer meet the specified performance requirement due to some induced condition and not due to its own internal failure pattern.

- Type 6 - this code indicates that maintenance resources were expended due to policy, modifications, item's location, cannibalization, or other 'no defect' conditions existing at the time maintenance was accomplished.

Mean Time Between Failure (MTBF) - The mean number of life unit (i.e., operating hours, flight hours, etc) during which all parts of the item perform within specified limits, during a particular measurement interval under stated conditions.

Mean Time Between Removals (MTBR) - Total number of system life units (i.e., operating hours, flight hours, etc) divided by the number of removals.

MODAS - The Maintenance and Operational Data Access System (MODAS) is an interactive Database Management System (DBMS) containing 24 months of field and depot reported operational (inventory, status, and utilization) and maintenance (AFR 66-1) data. The system is being developed primarily to support ALC System Program Managers (SPMs) and Inventory Managers (IMs). The database contains summarized files for obtaining Reliability and Maintainability information and detailed data files such as non-mission capable hours per flight hour, sorties, or landings by Command or Base.

Navy 3M Data System - Navy Maintenance Material Management System, output process data tapes and reports compiled in accordance with Navy Aviation Maintenance Program (NAMP-4790).

Off Equipment - Maintenance Actions that occur away from (off) end item article, e.g., intermediate repair shop.

On Equipment - Maintenance Actions that are exhibited at (on) end-item article, e.g., weapon system.

Percent Defective (d) - The number of defective units, divided by the number of units of product.

Process Average (μ) - The average number of defects per unit per specified interval of time (expressed in terms of removals in this guideline).

Removal Rate - Reciprocal of MTBR.

Removals - The number of items removed from a system during a stated period of time as related to demand for logistic support, and excluding removals performed to facilitate other maintenance, removals for product improvement, and removals for cannibalization.

Repairable - An item that can be restored to perform all its required functions by corrective maintenance.

Service Life - The duration of time an item experiences in operational inventory, including the performance of any maintenance act to keep the item in operating condition.

Shop Replaceable Unit (SRU) - An assembly or any combination of parts, subassemblies, and assemblies mounted together, normally capable of independent operation in a variety of situations and repairable at an ALC.

Specified MTBF(s) - Design or operational objective, as defined by handbook predicting techniques (i.e., MIL-HDBK-217), specified contractual goals (i.e., warranties), field operational objectives (i.e., R&M 2000 targets), or logistic planners, goals (i.e., wartime loading levels).

System - A group of interconnected electronic units which provides a specific function (e.g., radar system, navigation system, etc).

Tailoring - A process of environmental surveys required when the generic ESS environmental levels exceed the unit's functional design qualification levels. The potential exceedance levels are reduced or notched at resonant frequencies to eliminate structural and intermittant electrical problems.

Work Unit Code (WUC) - An alphanumeric code assigned to individual systems, subsystems, and equipment within a weapon system (aircraft, ground system, missile, etc) to track maintenance activities.

10.2 ACRONYMS & ABBREVIATIONS

AGREE - Advisory Group on Reliability of Electronic Equipment
AFC - Amortized Facility Cost
AFLC - Air Force Logistics Command
ALC - Air Force Logistics Center
AT - Action Taken
ATE - Automatic Test Equipment
CND - Cannot Duplicate
DR - Discrimination Ratio
DTC - Direct Test Cost
ESS - Environmental Stress Screening
HM - How Malfunction
ICS - Integrated Circuits
JCN - Job Control Number
LRU - Line Replaceable Unit
LSC - Logistic Support Cost
LSCS - Logistic Support Cost Savings
MTBF - Mean Time Between Failure
MTBR - Mean Time Between Removal
NOC - Not Otherwise Coded
PCB - Printed Circuit Board
ROI - Return on Investment
SRD - Standard Reporting Designation
SRU - Shop Replaceable Unit
TM - TM-Type Maintenance
WUC - Work Unit Code

APPENDIX A - LOGISTIC SUPPORT COST MODEL

The model used to determine downstream logistic support costs and cost savings resulting from application of ESS to an LRU/SRU was the USAF Logistic Support Cost (LSC) Model, Version 1.1. This widely used model developed for avionics systems uses algorithms and accounting equations which are documented in the AFLC User's Handbook. The model output included the following elements of logistic support:

- LRU/SRU spares
- On-equipment maintenance
- Off-equipment maintenance
- Inventory management
- Support equipment
- Training
- Management and technical data.

The model used approximately 52 input variables describing the system and maintenance scenario, and approximately 25 input variables describing each LRU. This input data was obtained from sources such as the manufacturer of the LRU, Air Force AFM 66-1 maintenance data, Air Force AFLCP 173-10, "AFLC Cost and Planning Factors," and AF Regulation 173-13 "USAF Cost and Planning Factors."

Tables A-1 and A-2 show the list's weapon system and system input variables used in the model for the three aircraft. Table A-3 shows the LRU input variables for the E-2C and F-14 avionic boxes. Table A-4 shows the LRU input variables for the EF-111A avionic boxes.

TABLE A-1. List of weapon system variables.

			F-14	E-2C	EF-111A
1.	IMC	INITIAL MANAGEMENT COST TO INTRODUCE NEW LINE ITEM OF SUPPLY (ASSEMBLY OR PIECE PART) INTO AIR FORCE INVENTORY (S) (AFLCR 173-10)	243.89	243.89	243.89
2.	M	NO. INTERMEDIATE REPAIR LOCATIONS (OPERATING BASES) (P) (SEE NOTE 2)	6	6	3
3.	MRF	AVG MANOURS PER FAILURE TO COMPLETE OFF-EQUIPMENT MAINTENANCE RECORDS (S = 0.24 HOURS)	0.24	0.24	0.24
4.	MRO	AVG MANHOURS PER FAILURE TO COMPLETE ON-EQUIPMENT MAINTENANCE RECORDS (S = 0.08 HOURS)	0.08	0.08	0.08
5.	NFLUSW	NO. FLU SOFTWARE PACKAGES WITHIN WEAPON SYSTEM (C) (ASSUMED)	0	0	0
6.	NSESW	NO. SE SOFTWARE PACKAGES WITHIN WEAPON SYSTEM (C) (ASSUMED)	0	0	0
7.	NSYS	NO. SYSTEMS WITHIN WEAPON SYSTEM (C) (NSYS = 1)	1	1	1
8.	OS	FRACTION OF TOTAL FORCE DEPLOYED TO OVERSEAS LOCATIONS (P) (SEE NOTE 2)	0.66	0.33	0.33
9.	OSTCON	WEIGHTED AVERAGE ORDER & SHIPPING TIME IN MONTHS. ELAPSED TIME BETWEEN INITIATION OF REQUEST FOR A SERVICEABLE ITEM & ITS RECEIPT BY REQUESTING ACTIVITY. FOR CONUS LOCATIONS LOCATIONS, S = 0.394 MONTHS (12 DAYS) INPUT AS OSTCON	0.39	0.39	0.39
9A.	OSTOS	SAME AS OSTCON EXCEPT FOR OVERSEAS LOCATIONS, S = 0.526 MONTHS (16 DAYS) INPUT AS OSTOS. (AFLCR 173-10): OST = (OSTCON) (1-OS) + (OSTOS) (OS)	0.53	0.53	0.53
10.	PFFH	PEAK FORCE FLYING HOURS – EXPECTED FLEET FLYING HOURS FOR ONE MONTH DURING PEAK USAGE PERIOD (P) (SEE NOTE 3)	1800.	3360.	1800.
11.	PIUP	OPERATIONAL SERVICE LIFE OF WEAPON SYSTEM IN YEARS (PROGRAM INVENTORY USAGE PERIOD) (ASSUMED PIUP = 15 YEARS)	15	15	25
12.	PMB	DIRECT PRODUCTIVE MANHOURS PER MAN PER YEAR AT BASE LEVEL (INCLUDES "TOUCH TIME," TRANSPORTATION TIME, AND SETUP TIME) (S = 1728 HOURS/MAN/YEAR) (AFLCR 173-10)	1728	1728	1728
13.	PMD	DIRECT PRODUCTIVE MANHOURS PER MAN PER YEAR AT DEPOT (INCLUDES "TOUCH TIME," TRANSPORTATION TIME, AND SETUP TIME) (S = 1728 HOURS/MAN/YEAR) (AFLCR 173-10)	1728	1728	1728
14.	PSC	AVG PACKING AND SHIPPING COST TO CONUS LOCATIONS (S) (AFLCR 173-10)	1.06	1.06	1.06
15.	PSO	AVG PACKING AND SHIPPING COST TO OVERSEAS LOCATIONS (S) (AFLCR 173-10)	2.19	2.19	2.19
16.	RMC	RECURRING MANAGEMENT COST TO MAINTAIN A LINE ITEM OF SUPPLY (ASSEMBLY OR PIECE PART) IN WHOLESALE INVENTORY SYSTEM (S) (AFLCR 173-10)	243.89	243.89	243.89
17.	SA	ANNUAL BASE SUPPLY LINE ITEM INVENTORY MANAGEMENT COST (S) (AFLCR 173-10)	12.31	12.31	12.31
18.	SR	AVG MANHOURS TO COMPLETE SUPPLY TRANSACTION RECORDS (S)	0.25	0.25	0.25
19.	TARGAVAL	BASE LEVEL SPARES AVAILABILITY OBJECTIVE FOR WEAPON SYSTEM (P) (ASSUMED TARGAVAL = 0.95)	0.95	0.95	0.95
20.	TD	AVG COST PER ORIGINAL PAGE OF TECHNICAL DOCUMENTATION. AVERAGE ACQUISITION COST OF ONE PAGE OF THE REPRODUCIBLE SOURCE DOCUMENT (DOES NOT INCLUDE REPRODUCTION COSTS) (S) (AFLCR 173-10)	306.51	306.51	306.51
21.	TFFH	EXPECTED TOTAL FORCE FLYING HOURS OVER PROGRAM INVENTORY USAGE PERIOD (P) (SEE NOTE 4)	203200	449280	324000
22	TR	AVG MANHOURS PER FAILURE TO COMPLETE TRANSPORTATION TRANSACTION FORMS (S = .16 HOURS)	0.16	0.16	0.16
23	TRB	ANNUAL TURNOVER RATE FOR BASE PERSONNEL (S = .134)	0.13	0.13	0.13
24	TRD	ANNUAL TURNOVER RATE FOR DEPOT PERSONNEL (S = .15)	0.15	0.15	0.15
25.	UEBASE	NO. UNIT EQUIVALENT WEAPON SYSTEMS PER OPERATING BASE (P)	60.	8	12.

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TABLE A-2. List of system variables (sheet 1 of 2).

			F-14	E-2C	EF-111A
1.	BCA	TOTAL COST OF ADDITIONAL ITEMS OF COMMON BASE SHOP SUPPORT EQUIPMENT PER BASE REQUIRED FOR SYSTEM (C) (BCA = 0)	0	0	0
2.	BAA	AVAILABLE WORK TIME PER MAN IN BASE SHOP IN MAN HOURS PER MONTH (S = 168 HOURS) (AFLCR 173-10)	168	168	168
3.	BLF	BASE LABOR RATE, INCLUDING INDIRECT LABOR, INDIRECT MATERIAL & OVERHEAD (S) (AFLCR 173-10)	22.27	22.27	22.27
4.	BMR	BASE CONSUMABLE MATERIAL CONSUMPTION RATE. INCLUDES MINOR ITEMS OF SUPPLY (NUTS, WASHERS, RAGES, CLEANING FLUID, ETC) CONSUMED DURING REPAIR OF ITEMS (S) (AFLCR 173-10)	3.23	3.23	3.23
5.	BPA	TOTAL COST OF PECULIAR BASE SHOP SUPPORT EQUIPMENT PER BASE REQUIRED FOR SYSTEM WHICH IS NOT DIRECTLY RELATED TO SPECIFIC FLUS OR WHEN QUANTITY REQUIRED IS INDEPENDENT OF ANTICIPATED WORKLOAD (SUCH AS OVERHEAD CRANES AND SHOP FIXTURES) (C) (BPA = 0)	0	0	0
6.	BRCT	AVG BASE REPAIR CYCLE TIME IN MONTHS. THE ELAPSED TIME FOR AN RTS ITEM FROM REMOVAL OF FAILED ITEM UNTIL IT IS RETURNED TO BASE SERVICEABLE STOCK (LESS TIME AWAITING PARTS). FOR FLUS OF THE "BLACK BOX" VARIETY (E.G., AVOINICS LRUs), THE REPAIR OF WHICH NORMALLY CONSISTS OF REMOVAL & REPLACEMENT OF "PLUG-IN" COMPONENTS (SRUs), S = 0.13 MONTHS (4 DAYS). (FOR OTHER NONMODULAR FLUs, S = 0.20 MONTHS (6 DAYS) (AFLCR 173-10) (BRCT = 0.13)	0.13	0.13	0.13
7.	CS	COST OF SOFTWARE TO UTILIZE EXISTING AUTOMATIC TEST EQUIPMENT FOR SYSTEM (C) (CS = 0)	0	0	0
8.	DCA	TOTAL COST OF ADDITIONAL ITEMS OF COMMON DEPOT SUPPORT EQUIPMENT REQUIRED FOR SYSTEM (C) (DCA = 0)	0	0	0
9.	DAA	AVAILABLE WORK TIME PER MAN AT DEPOT IN MANHOURS PER MONTH (S = 168 HOURS) (AFLCR 173-10)	168	168	168
10.	DLR	DEPOT LABOR RATE, INCLUDING OTHER DIRECT COSTS, OVERHEAD & G&A (S) (AFLCR 173-10)	38.44	38.44	38.44
11.	DMR	SAME AS BMR EXCEPT REFERS TO DEPOT LEVEL MAINTENANCE (S) (AFLCR 173-10)	11.78	11.78	11.78
12.	DPA	SAME AS BPA EXCEPT RELATED TO DEPOT SUPPORT EQUIPMENT (C) (DPA = 0)	0	0	0
13.	DRCT	WEIGHTED AVERAGE DEPOT REPAIR CYCLE TIME IN MONTHS. THE ELAPSED TIME FOR THE NRTS ITEM FROM REMOVAL OF FAILED ITEM UNTIL IT IS RETURNED TO DEPOT SERVICEABLE STOCK. INCLUDES TIME REQUIRED FOR BASE-TO-DEPOT TRANSPORTATION & HANDLING & SHOP FLOW TIME WITHIN SPECIALIZED REPAIR ACTIVITY REQUIRED TO REPAIR ITEM. FOR CONUS LOCATIONS, S = 1.73 MONTHS (52 DAYS) FOR ORGANIC REPAIR, S = 2.06 MONTHS (62 DAYS) FOR CONTRACTUAL REPAIR, INPUT AS DRCTC. FOR OVERSEAS LOCATIONS, S = 1.90 MONTHS (57 DAYS) FOR ORGANIC REPAIR, S = 2.20 MONTHS (66 DAYS) FOR CONTRACTUAL REPAIR, INPUT AS DRCTO (AFLCR 173-10) DRCT = (DRCT) (1-OS) + (DRCTO) (OS) (SEE NOTE 2)	1.73	1.73	1.73
14.	FB	TOTAL COST OF NEW BASE FACILITIES (INCLUDING UTILITIES) TO BE CONSTRUCTED FOR OPERATION & MAINTENANCE OF SYSTEM, IN DOLLARS PER BASE (C) (FB = 0)	0	0	0
15.	FD	TOTAL COST OF NEW DEPOT FACILITIES (INCLUDING UTILITIES), TO BE CONSTRUCTED FOR MAINTENANCE OF THE SYSTEM) (C) (FD = 0)	0	0	0
16.	FLA	TOTAL COST OF PECULIAR FLIGHT-LINE SUPPORT EQUIPMENT & ADDITIONAL ITEMS OF COMMON FLIGHT-LINE SUPPORT EQUIPMENT PER BASE REQUIRED FOR SYSTEM (C) (ASSUMED)	0	0	0

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TABLE A-2. List of system variables (sheet 2 of 2).

			F-14	E-2C	EF-111A
17.	H	NO. PAGES OF DEPOT LEVEL TECHNICAL ORDERS & SPECIAL REPAIR INSTRUCTIONS REQUIRED TO MAINTAIN SYSTEM (C) (ASSUMED)	0	0	0
18.	IH	COST OF INTERCONNECTING HARDWARE TO UTILIZE EXISTING AUTOMATIC TEST EQUIPMENT FOR SYSTEM (C) (IH = 0)	0	0	0
19.	JJ	NO. PAGES OF ORGANIZATIONAL & INTERMEDIATE LEVEL TECHNICAL ORDERS REQUIRED TO MAINTAIN SYSTEM (C) (ASSUMED)	0	0	0
20.	N	NUMBER OF DIFFERENT FLUs WITHIN SYSTEM (C)	4	1	6
21.	SMH	AVG MANHOURS TO PERFORM A SCHEDULED PERIODIC OR PHASED INSPECTION ON SYSTEM (C) (SMH = 0)	0	0	0
22.	SMI	FLYING HOUR INTERVAL BETWEEN SCHEDULED PERIODIC OR PHASED INSPECTIONS ON SYSTEM (C) (SEE NOTE 4)	NOTE 5	NOTE 5	NOTE 5
23.	SYSNOUN	NAME OF SYSTEM – UP TO 60 ALPHANUMERIC CHARACTERS (C)	XSYS	XSYS	XSYS
24.	TCB	COST OF PECULIAR TRAINING PER MAN AT BASE LEVEL INCLUDING INSTRUCTION & TRAINING MATERIALS (C) (SEE NOTE 6)	8495	8495	8495
25.	TCD	COST OF PECULIAR TRAINING PER MAN AT DEPOT INCLUDING INSTRUCTION & TRAINING MATERIALS (C) (SEE NOTE 6)	8495	8495	8495
26.	TE	COST OF PECULIAR TRAINING EQUIPMENT REQUIRED FOR SYSTEM (C) (SEE NOTE 6)	0	0	0
27.	XSYS	SYSTEM IDENTIFICATION, ASSIGNED FIVE-CHARACTER ALPHANUMERIC WORK UNIT CODE OF SYSTEM (C)	00000	00000	00000

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TABLE A-3. List of LRU variables (sheet 1 of 2).

	LINE REPLACEABLE UNITS-DEFINITIONS, SOURCES & RATIONALE	AIRCRAFT / VARIABLE	E-2C / SCRAM	F-14 / CSDC	CADC	VDIG	AICS
1.	AVG MANHOURS TO PERFORM SHOP BENCH CHECK, SCREENING & FAULT VERIFICATION ON REMOVED FLU PRIOR TO INITIATING REPAIR ACTION OR CONDEMNING THE ITEM (C) (3-M DATA)	BBCMH	7.7	6.0	8.2	6.9	7.4
2.	AVG COST PER FAILURE FOR FLU REPAIRED AT BASE LEVEL FOR STOCKAGE & REPAIR OF LOWER LEVEL ASSEMBLIES EXPRESSED AS A FRACTION OF FLU UNIT COST (UC). THIS IS THE IMPLICIT REPAIR, DISPOSITION COST FOR A FLU REPRESENTING LABOR, MATERIAL CONSUMPTION, & STOCKAGE REPLACEMENT OF LOWER INDENTURE REPAIRABLE COMPONENTS WITHIN THE FLU (e.g., SHOP REPLACEABLE UNITS OR MODULES (C) (SEE NOTE 6)	BMC	0.02	0.02	0.02	0.02	0.02
3.	AVG MANHOURS TO PERFORM INTERMEDIATE-LEVEL (BASE SHOP) MAINTENANCE ON REMOVED FLU INCLUDING FAULT ISOLATION, REPAIR, & VERIFICATION. (C) (3-M DATA)	BMH	10.4	8.1	10.7	12.5	10.5
4.	FRACTION OF REMOVED FLUs EXPECTED TO RESULT IN CONDEMNATION AT BASE LEVEL (C) (ASSUMED)	BCOND	0.01	0.01	0.01	0.01	0.01
5.	SAME AS BBCMH EXCEPT REFERS TO DEPOT-LEVEL MAINTENANCE (C) (3-M DATA)	DBCMH	7.7	6.0	8.2	6.9	7.4
6.	FRACTION OF FLUs RETURNED TO DEPOT FOR REPAIR (NRTS) EXPECTED TO RESULT IN CONDEMNATION OF DEPOT LEVEL (C) (ASSUMED)	DCOND	0.10	0.10	0.10	0.10	0.10
7.	SAME AS BMC ESCEPT REFERS TO DEPOT REPAIR ACTIONS (C) (SEE NOTE 6)	DMC	0.02	0.02	0.02	0.02	0.02
8.	SAME AS BMH EXCEPT REFERS TO DEPOT-LEVEL MAINTENANCE (C) (3-M DATA)	DMH	10.4	8.1	10.7	12.5	10.5
9.	WORD DESCRIPTION OR NAME OF THE FLU – UP TO 60 ALPHANUMERIC CHARACTERS (C)	FLUNOUN	SIGNAL COMMAND READOUT ALARM MODULE	COMPUTER SIGNAL DATA CONVERTER	CENTRAL AIR DATA COMPUTER	VERTICAL DISPLAY GROUP GROUP	AIR INLET CONTROL SYSTEM
10.	AVG MANHOURS TO PERFORM CORRECTIVE MAINTENANCE OF FLU IN PLACE OR INLINE WITHOUT REMOVAL INCLUDING FAULT ISOLATION, REPAIR & VERIFICATION (C) (3-M DATA)	IMH	2.9	4.6	6.8	3.9	10.4
11.	NO. LINE ITEMS OF PECULIAR SHOP SUPPORT EQUIPMENT USED IN REPAIR OF THE FLU (C)	K	1	1	1	1	1
12.	AVG MEAN TIME BETWEEN FAILURES IN OPERATING HOURS OF FLU IN OPERATION ENVIRONMENT WITHOUT ESS (C) (3-M DATA)	MTBF (W/O ESS)	2083	171	329	329	417
12A.	SAME AS 12 EXCEPT ESS INITIALLY APPLIED TO EACH LRU (C) (3-M DATA)	MTBF (W/ESS)	3571	446	735	595	894
13.	FRACTION OF REMOVED FLUs EXPECTED TO BE RETURNED TO THE DEPOT FOR REPAIR (C) (SEE NOTE 5)	NRTS	.01	0.02	0.02	0.01	0.01
14.	NEW "P" CODED REPAIRABLE ASSEMBLIES WITHIN THE FLU (C) (SEE NOTE 6)	PA	8	10	14	55	15
15.	AVG MANHOURS EXPENDED IN PLACE ON INSTALLED SYSTEM FOR PREPARATION &ACCESS VFOR FLU; FR EXAMPLE, JACK-ING, UNBUTTONING, REMOVAL OF OTHER UNITS AND HOOKUP OF SUPORT EQUIPMENT (C) (3-M DATA)	PAMH	1.	3.6	8.7	5.2	2.8
16.	NO. NEW "P" CODED CONSUMABLE ITEMS WITHIN THE FLU (C) (SEE NOTE 6)	PP	0	0	0	0	0
17.	QUANTITY OF LIKE FLUs WITHIN PARENT SYSTEM (QUANTITY PER APPLICATIONS (C)	QPA	6	1	1	1	1

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TABLE A-3. List of LRU variables (sheet 2 of 2).

		AIRCRAFT	E-2C	F-14			
	LINE REPLACEABLE UNITS-DEFINITIONS, SOURCES & RATIONALE	VARIABLE	SCRA'J	CSDC	CADC	VDIG	AICS
18.	FRACTION OF FLU FAILURES WHICH CAN BE REPAIRED IN PLACE OR ON LINE WITHOUT REMOVAL (C) (3-M DATA)	RIP	0.23	0.13	0.13	0.09	0.13
19.	AVG MANHOURS TO FAULT ISOLATE, REMOVE, AND REPLACE FLU ON INSTALLED SYSTEM & VERIFY RESTORATION OF SYSTEM TO OPERATIONAL STATUS (C) (3-M DATA)	RMH	2.7	5.1	5.0	5.3	4.8
20.	FRACTION OF REMOVED FLUs EXPECTED TO BE REPAIRED AT BASE LEVEL (C) (3-M DATA)	RTS	0.98	0.98	0.98	0.99	0.99
21.	NO. STANDARD (ALREADY STOCK-NUMBERED) PARTS WITHIN FLU WHICH WULL BE MANAGED FOR FIRST TIME AT BASES WHERE THIS SYSTEM IS DEPLOYED (C) (SEE NOTE 6)	SP	0	0	0	0	0
22.	EXPECTED UNIT COST OF THE FLU AT TIME OF INITIAL PROVISIONING (C) (ESTIMATES BY SUPPLY OPERATIONS ANALYSTS)	UC	55217	312008	82038	162932	26180
23.	RATIO OF OPERATING HOURS TO FLYING HOURS FOR FLU (USE FACTOR) (C) (UF = 1.25 – ASSUMED)	UF	1.25	1.25	1.25	1.25	1.25
24.	FLU UNIT WEIGHT IN POUNDS (C) (DESIGN SPECIFICATIONS)	W	8.0	41.7	33.2	81.75	75.95
25.	FLU IDENTIFICATION. THE ASSIGNED FIVE-CHARACTER ALPHANUMERIC WORK UNIT CODE OF THE FLU (C) (USED WUC WHEN AVAILABLE)	XFLU	58211	56X44	56X25	69182	29X11

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TABLE A-4. List of LRU variables – 2.

	LINE REPLACEABLE UNITS-DEFINITIONS, SOURCES, & RATIONALE	AIRCRAFT VARIABLE	EF-111A DDO	EF-111A SDC	EF-111A RIRI	EF-111A CSU	EF-111A MBE	EF-111A RFC
1.	AVG MANHOURS TO PERFORM SHOP BENCH CHECK, SCREENING, & FAULT VERIFICATION ON REMOVED FLU PRIOR TO INITIATING REPAIR ACTION OR CONDEMNING ITEM (C) (3 M DATA)	BBCMH	2.50	6.0 1.50	2.50	6.9 2.50	7.4 7.0	2.00
2.	AVC COST PER FAILURE FOR FLU REPAIRED AT BASE LEVEL FOR STOCKAGE & REPAIR OF LOWER LEVEL ASSEMBLIES EXPRESSED AS A FRACTION OF FLU UNIT COST (UC). THIS IS THE IMPLICIT REPAIR DISPOSITION COST FOR FLU REPRESENTING LABOR, MATERIAL CONSUMPTION, & STOCKAGE/REPLACEMENT OF LOWER INDENTURE COMPONENTS WITHIN THE FLU (E G., SHOP REPLACEABLE UNITS OR MODULES (C) (SEE NOTE 6)	BMC	0.02	0.02	0.02	0.02	0 02	0.02
3.	AVG MANHOURS TO PERFORM INTERMEDIATE LEVEL (BASE SHOP) MAINTENANCE ON A REMOVED FLU INCLUDING FAULT ISOLATION, REPAIR & VERIFICATION (C) (3 M DATA)	BMH	3.50	2.50	3.50	3.50	9.00	3.00
4.	FRACTION OF REMOVED FLUs EXPECTED TO RESULT IN CONDEMNATION AT BASE LEVEL (C) (ASSUMED)	BCOND	0.00	0.00	0 00	0.00	0.00	0.00
5.	SAME AS BBCMH EXCEPT REFERS TO DEPOT-LEVEL MAINTENANCE (C) (3-M DATA)	DBCMH	2.50	1.50	2 50	2.50	7.0	2.00
6.	FRACTION OF FLUs RETURNED TO DEPOT FOR REPAIR (NRTS) EXPECTED TO RESULT IN CONDEMNATION OF DEPOT LEVEL (C) (ASSUMED)	DCOND	0.00	0.00	0 00	0.00	0.00	0.00
7.	SAME AS BMC EXCEPT REFERS TO DEPOT REPAIR ACTIONS (C) (SEE NOTE 6)	DMC	0.02	0.02	0.02	0.02	0.02	0.02
8.	SAME AS BMH EXCEPT REFERS TO DEPOT-LEVEL MAINTENANCE (C) (3-M DATA)	DMH	3.50	2.50	3.50	3.5	9.00	3.00
9.	WORD DESCRIPTION OR NAME OF THE FLU – UP TO 60 ALPHANUMERIC CHARACTERS (C)	FLUNOUN	DITITAL DATA INDICATOR	SIGNAL DATA CONVERTER	RADAR IR INDICATOR	COMPUTER SYNC UNIT	EXCITER	RF CALIBRATOR
10.	AVG MANHOURS TO PERFORM CORRECTIVE MAINTENANCE OF FLU IN PLACE OR IN LINE WITHOUT REMOVAL INCLUDING FAULT ISOLATION, REPAIR & VERIFICATION (C) (3-M DATA)	IMH	0.50	0.5C	0.50	0.50	0.50	0.50
11.	NO. LINE ITEMS OF PECULIAR SHOP SUPPORT EQUIPMENT USED IN REPAIR OF FLU (C)	K	0	0	0	0	0	0
12.	AVG MEAN TIME BETWEEN FAILURES IN OPERATING HOURS OF THE FLU IN OPERATION ENVIRONMENT WITHOUT ESS (C) (3-M DATA)	MTBF (W/O ESS)	257	129	85	85	30	67
12A.	SAME AS 12 EXCEPT ESS INITIALLY APPLIED TO EACH LRU (C) (3-M DATA)	MTBF (W/ESS)	514	258	170	170	60	134
13.	FRACTION OF REMOVED FLUs EXPECTED TO BE RETURNED TO DEPOT FOR REPAIR (C) (SEE NOTE 5)	NRTS	0.06	0.06	0.06	0.06	0.06	0.06
14.	NO. OF NEW "P" CODED REPAIRABLE ASSEMBLIES WITHIN THE FLU (C) (SEE NOTE 6)	PA	8	8	8	8	8	8
15.	AVG MANHOURS EXPENDED IN PLACE ON INSTALLED SYSTEM FOR PREPARATION & ACCESS FOR FLU; FOR EXAMPLE, JACKING, UNBUTTONING, REMOVAL OF OTHER UNITS & HOOKUP OF SUPPORT EQUIPMENT (C) (3-M DATA)	PAMH	0.05	0.05	0.05	0.05	0.05	0.05
16.	NO. NEW "P" CODED CONSUMABLE ITEMS WITHIN FLU (C) (SEE NOTE 6)	PP	30	30	30	30	30	30
17.	QUANTITY OF LIKE FLUs WITHIN PARENT SYSTEM (QUANTITY PER APPLICATIONS) (C)	QPA	1	1	1	1	1	1
18.	FRACTION OF FLU FAILURES WHICH CAN BE REPAIRED IN PLACE OR ON LINE WITHOUT REMOVAL (C) (3-M DATA)	RIP	0.05	0.05	0.05	0.05	0.05	0.05
19.	AVG MANHOURS TO FAULT ISOLATE, REMOVE, AND REPLACE FLU ON INSTALLED SYSTEM AND VERIFY RESTORATION OF SYSTEM TO OPERATION STATUS (C) (3-M DATA)	RMH	2.0	2.0	2.0	2.0	2.0	2.0
20.	FRACTION OF REMOVED FLUs EXPECTED TO BE REPAIRED AT BASE LEVEL (C) (3-M DATA)	RTS	0.94	0.94	0.94	0.94	0.94	0.94
21.	NO. STANDARD (ALREADY STOCK-NUMBERED) PARTS WITHIN FLU WHICH WILL BE MANAGED FOR FIRST TIME AT BASES WHERE THIS SYSTEM IS DEPLOYED (C) (SEE NOTE 6)	SP	16	16	16	16	16	16
22.	EXPECTED UNIT COST OF FLU AT TIME OF INITIAL PROVISIONING (C) (ESTIMATES BY SUPPLY OPERATIONS ANALYSIS)	UC	115508	401300	302420	444250	486900	173700
23.	RATIO OF OPERATING HOURS TO FLYING HOURS FOR FLU (USE FACTOR) (C) (UF = 1.25 – ASSUMED)	UF	1.25	1.25	1.25	1.25	1.25	1.25
24.	FLU UNIT WEIGHT IN POUNDS (C) (DESIGN SPECIFICATIONS)	W	47	58	23	84	115	42
25.	FLU IDENTIFICATION. THE ASSIGNED FIVE-CHARACTER ALPHANUMERIC WORK UNIT CODE OF THE FLU (C) (USED WUC WHEN AVAILABLE)	XFLU	76Y10	76Y02	73BR0	76Y50	76ZM0	76ZPU

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NOTES TO LIST OF WEAPON, SYSTEM & LRU VARIABLES

Note 1: (C) = Contractor-furnished value

(S) = Government-furnished standard value

(P) = Program-peculiar value

(AFLCR 173-10) = denotes data source is AFLCR 173-10 "AFLC Cost and Planning Factors"

Note 2: Assumption:

A total of 360 F-14 aircraft will be deployed with 60 each at Miramar and Oceana and on each of four aircraft carriers. Therefore, OS = 0.66 for the F-14.

A total of 48 E-2C aircraft will be deployed with 16 each at Miramar and Oceana and four each aboard four aircraft carriers. Therefore, OS = 0.33 for the E-2C.

A total of 36 EF-111A aircraft will be deployed with 12 each at three bases, one base being overseas. Therefore, OS = 0.33 for the EF-111A.

Note 3: Assumption:

F-14 Peak Flying Hours = 50 hours per aircraft per month. Therefore Peak Force Flying Hours = 50 hours x 360 aircraft = 18,000 hours.

E-2C Peak Flying Hours = 70 hours per aircraft per month. Therefore Peak Force Flying Hours = 70 hours x 48 aircraft = 3660 hours.

EF-111A Peak Flying Hours = 50 hours per aircraft per month. Therefore Peak Force Flying Hours = 50 hours x 36 aircraft = 1800 hours.

Note 4: Assumption:

F-14 Average Flying Hours = 34 hours per aircraft per month and operational service life = 15 years. Therefore Total Force Flying Hours = 34 hours x 12 months x 15 years x 360 aircraft = 2,203,200.

E-2C Average Flying Hours = 52 hours per aircraft per month and the operational service life = 15 years. Therefore Total Force Flying Hours = 52 hours x 12 months x 15 years x 48 aircraft = 449,280 hours.

EF-111A Average Flying Hours = 30 hours per aircraft per month and the operational service life = 15 years. Therefore Total Force Flying Hours = 30 hours x 12 months x 15 years x 36 aircraft = 194,400 hours. For an operational service life of 25 years, the TFFH = 324,000 hours.

Note 5: The LRUs on the F-14, E-2C, and EF-111A were assumed to have no scheduled periodic or phased inspections. Therefore, the interval between them was infinite so that a value of 999,999,999 was used.

Note 6: BMC and DMC = 0.02 is used for all LRUs. The value is based on data of the F-16 "Logistic Support Cost Status Report (UL 76AQ)," 15 June 1981 for similar equipment.

Note 7: Average numbers for PA, PP, and SP were estimated by our Supply Operations analysts.

APPENDIX B - HIGH RANK REMOVAL LRUs
EF-111A (June 1984 - July 1986)

Rank	WUC	Removals**	MFHBR*
1	76ZMO	662	31
2	76ZKO	616	33
3	76ZGO	547	37
4	73ABO	380	53
5	65ACL	354	57
6	73AAO	327	62
7	76ZPO	302	67
8	73KBO	277	73
9	73CAO	275	74
10	76ZEO	246	83
11	73 3RO	239	85
12	76Y5O	232	88
13	76TDO	203	100
14	73BDO	188	108
15	52BAA	181	112
16	52AOA	179	114
17	76Y2O	153	133
18	73KKO	135	150
19	51ABG	133	153
20	61CAO	129	157
21	73BKO	115	177
22	76WEO	111	183
23	51CCO	106	192
24	52BCC	104	195
25	76TCO	98	207
26	64BCE	95	214
27	64BCE	89	228
28	73DFO	87	234
29	63CAO	84	242

Rank	WUC	Removals**	MFHBR*
30	73CAP	80	254
31	76Y10	79	257
32	76WDO	76	267
33	51ABA	64	317

* Flight Hours - 20,317

** Type 1 + Type 2 + Type 6

APPENDIX C

FIELD ESS IMPLEMENTATION GUIDELINES

CONTENTS

CONTENTS (contd)

ILLUSTRATIONS

TABLES

1 - SCOPE

This document establishes Environmental Stress Screening (ESS) guidelines and application/decision criteria for equipment already operating in a service environment. The objective is to enable the Air Force Logistics Center's (ALC) Item Managers to determine the most cost effective approach to introducing ESS on field-repaired equipment and to establish policy for inventoried equipment which was not subjected to ESS. The major emphasis of this guideline document is to establish how and where ESS can be most practically and effectively applied within the current Air Force maintenance organization utilizing the AFM 66-1 documentation. The most significant benefit of this effort to the Air Force is the potential for improving equipment field reliability and thereby the readiness performance of the end-item weapon system, as well as significant reductions in logistic support costs.

Before using the subject guidelines, it is extremely important to appreciate the differences between ESS of new and in-service or inventoried equipment. On new equipment, the designer has the opportunity to include in the equipment's design the test criteria for all of the environments to which the equipment will later be subjected. However, inventoried equipment becomes the responsibility of the Item Manager. He must gather the information on the equipment's environmental qualification capabilities, its past and current operational performance, the use environment, and its reliability characteristics. The latter information is necessary for the Item Manager to form the minimum baseline for establishing the need to perform any field ESS at the cognizant ALC.

Field ESS is an end-item Quality Assurance test being performed in a non-homogeneous product control environment. Service life build-up and repeated repair of this equipment will have affected lot homogenity, component, and lower level of assembly process controls, as well as identifiable configuration control. The objective of this guideline, therefore, is to establish a screening program which will identify, select, and optimally screen only those units that will provide the most potential for reducing the aggregate removal rates. These rates may result from

persistent workmanship defects induced either in the initial manufacturer's process or through repeated removal and repair of the unit during its operational life.

The guideline is structured to provide the Item Manager with a step by step procedure to insure that only the most technically sound and cost effective approaches are given due consideration. As shown in Fig. C-1, the established ESS selection program is divided into four major areas:

(1) Equipment Selection - based on existing AFD056 and MODAS databases and supporting ALC data, establishes equipment population and maintenance rate histories sensitive to ESS

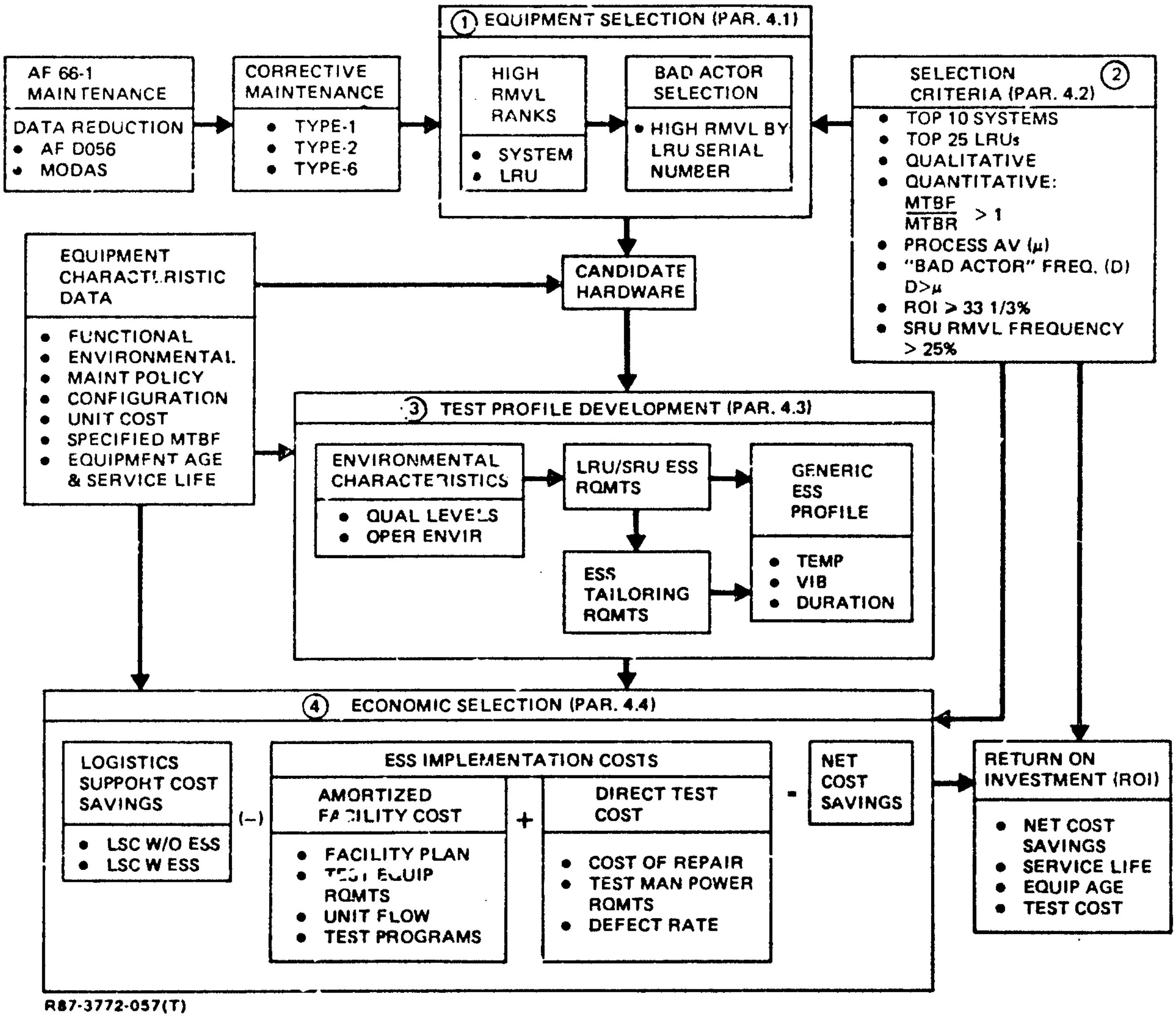


Figure C-1. Field ESS implementation program task flow.

(2) Selection Criteria - establishes selection means to minimize the quantity and quality of the equipment selected for testing

(3) Test Profile Development - obtains equipment's environmental qualification and operational capabilities, and establishes temperature and vibration levels and durations which include test tailoring practices and considerations

(4) Economic Selection - conducts cost studies to optimize facility, test equipment, manhours, and test requirements to accurately assess all costs to determine if a Return on Investment (ROI) savings is obtainable.

The task flow provided in Fig. C-1 delineates what must be accomplished, as a minimum, to develop an effective and economically viable program as discussed in the subsequent paragraphs of this guideline.

2 · REFERENCE DOCUMENTS

2.1 GOVERNMENT DOCUMENTS

Specifications

MIL-M-38769	Work Unit Code Construction and Application

Standards

MIL-STD-109	Quality Assurance Terms and Definitions
MIL-STD-721	Definition of Terms for Reliability and Maintainability
MIL-STD-2164(EC)	Environmental Stress Screening Process for Electronic Equipment

Handbooks

MIL-HDBK-217	Reliability Prediction of Electronic Equipment
MIL-HDBK-344 (USAF)	Environmental Stress Screening of Electronic Equipment

Publications

Air Force

LSC Model Version 1.1	Logistic Support Cost Model User's Handbook
AFFDL-TR-71-32	Analysis of Aeronautical Equipment Environmental Failures
TO-00-20-2	Maintenance Data Collection System Manual

Navy

NAVMAT P-9492	Navy Manufacturing Screening Program

2.2 NON-GOVERNMENT DOCUMENTS

Institute of Environmental Sciences (IES)

Environmental Stress Screening Guidelines for Assemblies, September 1984.

3 - DEFINITIONS & ACRONYMS

3.1 DEFINITIONS APPLICABLE TO GUIDELINES

AFD056 - Output process data tapes and reports compiled in accordance with D056 Data System directive for reporting AF66-1 Maintenance Data Collection.

Bad Actor or Loser Box - Units of product which have a frequency of removals greater than the norm or process average.

Consumable - An item of material used up beyond recovery in the use for which it was designed or intended.

Defect - Any non-conformance of the unit of product with specified requirements.

Defective - Is a unit of product which contains one or more defects.

Discrimination Ratio (DR) - The measure of steepness between specified MTBF(s) and MTBR to discriminate between high and low product defective potential. Numerically

- $\frac{MTBF(s)}{MTBR} \leq 1$; low potential
- $\frac{MTBF(s)}{MTBR} > 1$; high potential

Environmental Stress Screening (ESS) - A series of environmental tests conducted to disclose weak parts, workmanship defects and manufacturing process anomalies.

ESS Test Profile - The sequence and duration of stress environments under which item is to be subjected.

Failure Free Time - A contiguous period of time (in terms of environmental cycles) during which an item is to operate without the occurrence of a failure while under environmental stress.

Failure Rate - Reciprocal of MTBF.

Field ESS - ESS performed by a cognizant equipment ALC, in lieu of a manufacture at the manufacturer's facility.

Inherent Defect - A failure or defect that is a function of the intended design application of the item, when operated in its intended operational and logistic support environment.

Latent Defect - A process induced (manufacturing, quality, maintenance) weakness, not detected by ordinary means, which will either be precipitated by ESS screening conditions or eventually fail in its intended use environment.

Line Replaceable Unit (LRU) - A unit normally removed and replaced as a single item which consists of assemblies (SRUs), accessories, and components that collectively perform a specific functional operation.

Maintenance Action - An element of a maintenance event. One or more tasks (e.g., removal, fault detection, fault isolation, repair and inspection) necessary to retain an item in, or restore to, a specific condition.

Maintenance Event - One or more maintenance actions required to effect corrective maintenance due to any type of failure, or malfunction, false alarm. Categorization of maintenance events based on the D056 Air Force definition is as follows:

- Type 1 - this code indicates that the item can no longer meet the minimum specified performance requirements due to its own internal failure pattern
- Type 2 - this code indicates that the item can no longer meet the specified performance requirement due to some induced condition and not due to its own internal failure pattern
- Type 6 - this code indicates that maintenance resources were expended due to policy, modifications, item's location, cannibalization, or other 'no defect' conditions existing at the time maintenance was accomplished.

Mean Time Between Failure (MTBF) - The mean number of life units (i.e., operating hours, flight hours, etc) during which all parts of the item perform within specified limits, during a particular measurement interval under stated conditions.

Mean Time Between Removals (MTBR) - Total number of system life units (i.e., operating hours, flight hours, etc) divided by the number of removals.

MODAS - The Maintenance and Operational Data Access System (MODAS) is an interactive Database Management System (DBMS) containing 24 months of field and depot reported operational (inventory, status, and utilization) and maintenance (AFR 66-1) data. The system is being developed primarily to support ALC System Program Managers (SPMs) and Inventory Managers (IMs). The database contains summarized files for obtaining Reliability and Maintainability information and detailed data files such as non-mission capable hours per flight hour, sorties, or landings by Command or Base.

Percent Defective (d) - The number of defective units, divided by the number of units of product.

Process Average (μ) - The average number of defects per unit per specified interval of time (expressed in terms of removals in this guideline).

Removal Rate - Reciprocal of MTBR.

Removals - The number of items removed from a system during a stated period of time as related to demand for logistic support, and excluding removals performed to facilitate other maintenance, removals for product improvement, and removals for cannibalization.

Repairable - An item that can be restored to perform all its required functions by corrective maintenance.

Service Life - The duration of time an item experiences in operational inventory, including the performance of any maintenance act to keep the item in operating condition.

Shop Replaceable Unit (SRU) - An assembly or any combination of parts, subassemblies, and assemblies mounted together, normally capable of independent operation in a variety of situations and repairable at an ALC.

Specified MTBF(s) - Design or operational objective, as defined by handbook predicting techniques (i.e., MIL-HDBK-217), specified contractual goals (i.e., warranties), field operational objectives (i.e., R&M 2000 targets), or logistic planners, goals (i.e., wartime loading levels).

System - A group of interconnected electronic units which provide a specific function (e.g., radar system, navigation system, etc).

Tailoring - A process of environmental urveys required when the generic ESS environmental levels exceed the unit's functional design qualification levels. The potential exceedance levels are reduced or notched at resonant frequencies to eliminate structural and intermittent electrical problems.

Work Unit Code (WUC) - An alphanumeric code assigned to individual systems, subsystems, and equipment within a weapon system (aircraft, ground system, missile, etc) to track maintenance activities.

3.2 ACRONYMS & ABBREVIATIONS

AFC - Amortized Facility Cost
ALC - Air Force Logistics Center
ATE - Automatic Test Equipment
DR - Discrimination Ratio
DTC - Direct Test Cost
ESS - Environmental Stress Screening
ICS - Integrated Circuits
LRU - Line Replaceable Unit
LSC - Logistic Support Cost
LSCS - Logistic Support Cost Savings
MTBF - Mean Time Between Failure
MTBR - Mean Time Between Removal
ROI - Return on Investment
SRD - Standard Reporting Designation
SRU - Shop Replaceable Unit
WUC - Work Unit Code

4 - GUIDELINES

In a field ESS scenario, the Line Replaceable Unit (LRU) provides the only basis of continuity for controlling the non-homogeneous state of field hardware configuration, age, and maintenance history. The justification for this includes:

- The LRU is the focal point of all field maintenance reporting and provides reasonable traceability to establish quality characteristics, including measurable removal rates and individual unit traceability
- It is the functional basis of performance for which support equipment is available to permit complete operational diagnosis of any performance parameters
- The integrated functional capability permits diagnosis of intermittent workmanship defects, which constitute approximately 50% of all defects encountered during ESS screening
- There is no process control in a field maintenance scenario that can replace all levels of assembly at one time (short of an overhaul), and provide a homogeneous quality level. On a per repair basis, the resulting effects of lower level assembly ESS become inconsequential and are highly sensitive to:
  - The true number of defects that exist in the LRU, and how they are distributed in the lower levels of assembly
  - The number of times the LRU is actually repaired in its lifetime
- Since the LRU is a potential collection point for quality related problems, and the maintenance reporting is identifiable at that level, it provides a means for monitoring and selecting LRUs that tend to demonstrate higher than normal removal frequencies. This selection process provides the means for managing the amount of testing that would normally be required if all the units in the population had to be tested
- The focal point for Logistic Support Cost Analysis and trade-off is the LRU. If potential yields are not sufficient to affect the removal rates improvement at that level, the effective cost benefit Return on Investment (ROI) for the ESS testing cannot be justified.

For these reasons the hardware basis of these guidelines is the LRU, and the quantitative measures will be a function of their field maintenance removal rate. Subsequent selection for testing at lower levels of assembly (e.g., SRUs, components) will be a function of the LRU's selection performance. The primary processes of selection are:

(1) Establishment Of High Contributor Lists (4.1)
- High removal rate contributors

(2) Selection Criteria (4.2)
- Qualitative
- Quantitative
- High bad actor selection

(3) Test Profile Development (4.3)
- Environmental characteristics
- ESS profile
- LRU ESS requirements
- SRU ESS requirements
- ESS tailoring
- Generic ESS test recommendations

(4) Economic Selection Criteria (4.4)
- Logistics Support Cost Savings
- Test Implementation Cost
- Comparative Return on Investment.

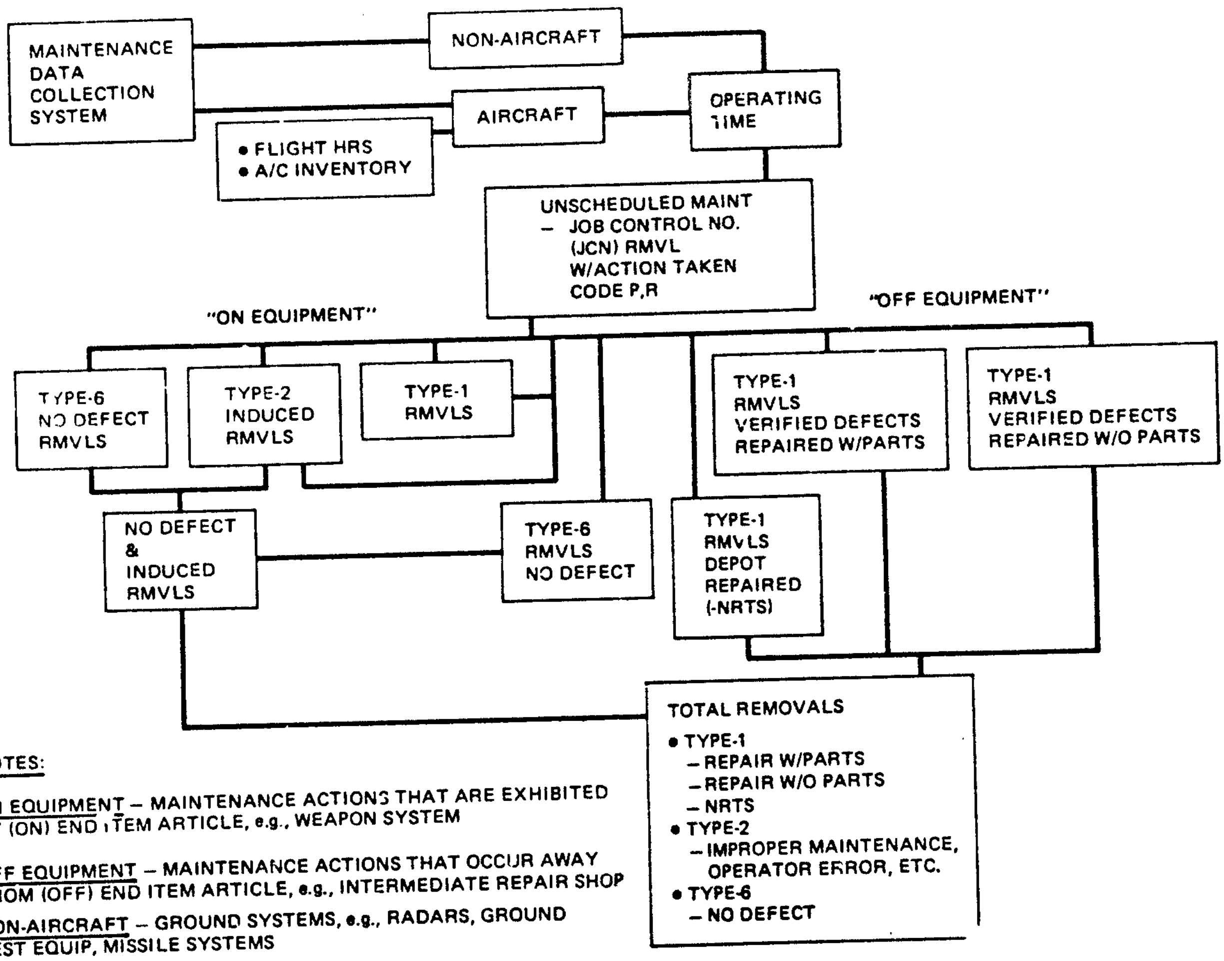
The objective of the test planning will be achieved when the highest possible percentage improvement in the field removal rate is attained by:

- Selecting and testing, optimally, the lowest number, type, and kind of units possible
- Establishing the optimal ESS profile and duration that can be applied to a field aged unit, without compromising equipment life or test stimulation effectiveness.

A high level of success is thereby insured, within the lowest test risk and with minimized test implementation cost, while improving the field reliability and logistic support cost savings.

4.1 ESTABLISHING HIGH CONTRIBUTOR LISTS

Prioritization of ESS candidates from field inventory for incorporation into the ALC depot repair process will be based on equipment field maintenance histories as compiled from the Air Force's D056 Field Maintenance Data Base, and supplemental repair data as maintained by the equipment responsible ALC. The selection criteria consists of those indicators and parameters which can be used for tracking equipment maintenance performance, and enable selection of equipment or groups of equipment and lower levels of assembly that offer the most potential for producing positive aggregate improvement to both the equipment and the weapon system. Figure C-2 provides the field data reduction flow necessary to provide the removal accountability.



NOTES:

ON EQUIPMENT – MAINTENANCE ACTIONS THAT ARE EXHIBITED AT (ON) END ITEM ARTICLE, e.g., WEAPON SYSTEM

OFF EQUIPMENT – MAINTENANCE ACTIONS THAT OCCUR AWAY FROM (OFF) END ITEM ARTICLE, e.g., INTERMEDIATE REPAIR SHOP

NON-AIRCRAFT – GROUND SYSTEMS, e.g., RADARS, GROUND TEST EQUIP, MISSILE SYSTEMS

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Figure C-2. Field data reduction.

4.1.1 High Removal Rate Contributors

High removals for cause provides the initial basis for selection of candidate hardware.

The equipment's high removal performance is based on those Job Control Numbered (JCN) actions resulting in an unscheduled removal (action taken codes (P, R)), resulting in the following maintenance actions:

- Type 1 Maintenance Actions (as defined by AFLCR66-15) resulting in:
  - Repair action with parts, as concluded by an H and P record
  - Repair action without parts
  - Repair action resulting in NRTS (Not Repairable This Station)
- Type 2 (Induced Maintenance) Maintenance Actions (as defined by AFLCR66-15)
- Type 6 (Cannot Duplicate) Maintenance Actions (as defined by AFLCR66-15), excluding (How Mal Code 800 Series Codes)
  - Removals for access and upgrading
  - Removals for cannibalization.

Total maintenance removals (R), are the sum of the type maintenance actions:

(R) = Type 1 + Type 2 + Type 6

4.1.1.1 System Selection - System level candidates (e.g., radar system, navigation system, etc) will be drawn from those categories that define electronic and electromechanical systems, equipment, and assemblies. Typically, Work Unit Code (WUC) Categories 5 (Instrumentation/Navigation), 6 (Communications/Navigation), and 7 (Weapon System) for aircraft are as defined per specific weapon system WUC manuals. The basis of total removals considered will be summed from those categories.

For non-aircraft systems (ground systems, test equipment, missile systems, etc), the WUC designation and structure are as defined for the specific Standard Reporting Designation (SRD) code for that system. The equipment, LRU, and lower level structure are as defined in MIL-M-38769 (Work Unit Code Construction and Application). The SRD provides the access code for selection of the maintenance data available in the D056 and MODAS databases. The SRDs for all reportable systems are provided in the Maintenance Data Collection System Manual TO-00-20-2.

The WUC structures are similar to those of aircraft in that they report up to five digit levels. As an example, the AN/GKC-1(V) Satellite Tracking Set has an SRD of (L4HG). A portion of the WUC structure identified for this system as reported in MODAS includes the alphanumeric codes defined as follows:

AQXXX (2 digit) (System)
AQEXX (3 digit) (Equipment)
AQEPX (4 digit) (LRU Level)
AQEPH (5 digit) (SRU Level)

This is similar to aircraft reporting, with the difference that all aircraft systems start with numeric prefixes.

In the AFD056 data system, the system level is generally defined by the three digit WUC level, or to the level which will appropriately define the military designation nomenclature (e.g., AN/APQ, ALQ, etc). The prioritization of the system will be by its ranking based on total removals. Based on studies of high density avionic weapon systems, Fig. C-3 provides the cumulative average removal distribution

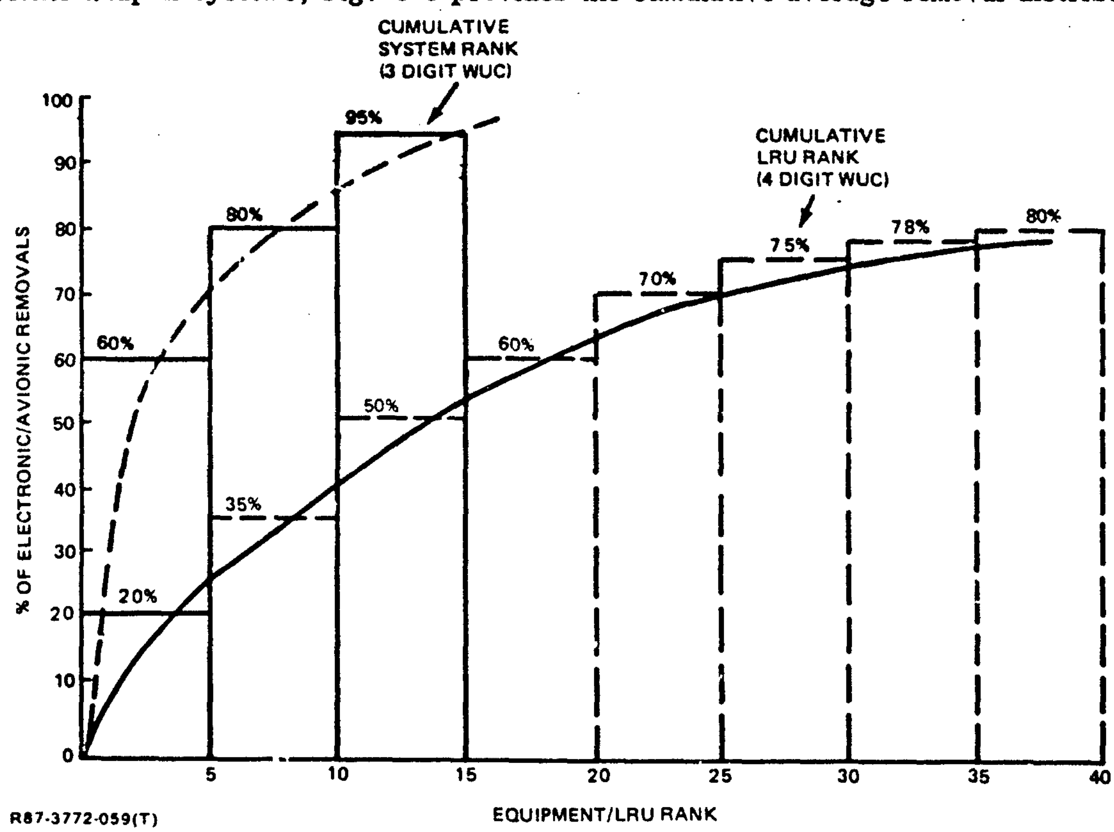

Figure C-3. Average top down rank distribution of electronic/avionic system & LRUs.

for equipment and LRU rankings by removals. Nominally, 90% of electronic equipment removals are within the top ten ranked by removal. This is true of the non-aircraft systems as well, and is a function of the type of equipment being described. In all cases, only electronic type hardware should be selected for ranking.

4.1.1.2 Line Replaceable Unit (LRU) Selection - Candidate LRUs, typically defined by the four digit WUC level, should be selected from the population of systems defined in Subsection 4.1.1.1. The prioritization of selected LRUs will be by their ranking by total removals. The number of LRUs considered should be within the 70-75% removal range; beyond that point the rate of removal contribution per LRU is negligible. This will provide a selection within the top 25 LRU's as noted in Fig. C-3.

4.1.1.3 Shop Replaceable Unit (SRU) Selection - The AFP056 database provides little in the traceability of SRUs. They are normally reported at the five digit WUC level, and are generally Not Repairable This Station (NRTS) and sent to a cognizant ALC for repair and disposition. Further, they are not, or are rarely, identifiable by serial number and accountability is extremely difficult. However, SRUs are the current basis for ALC repair operations. Thus, selecting an SRU for ESS should be based on its contribution to the LRU's removal rate. The higher the frequency, the more significant the SRU.

Figure C-4 provides a decision making aid for identifying candidate SRU or lower levels of assembly effects on the LRU based on the SRU's removal contribution. The abscissa (X axis) is the ratio of total removals contributed by the SRU or lower level of assembly. The ordinate (Y axis) on the right side of the graph provides the potential improvement achievable by the SRU or lower level of assembly as a result of screening. A 100% improvement is a virtual elimination of the component as a removal rate contributor. The left ordinate is the corresponding improvement that is achievable at the LRU level based on the achieved SRU or lower level improvement. As an example, if an SRU or lower level of assembly contributes 50% of the total LRU removals, eliminating it completely (or 100% improvement) cannot improve the LRU any more than 50% since you cannot gain more than you put in. Similarly, if the screen of the SRU is only 50% effective, then the LRU improvement can only be 25%.

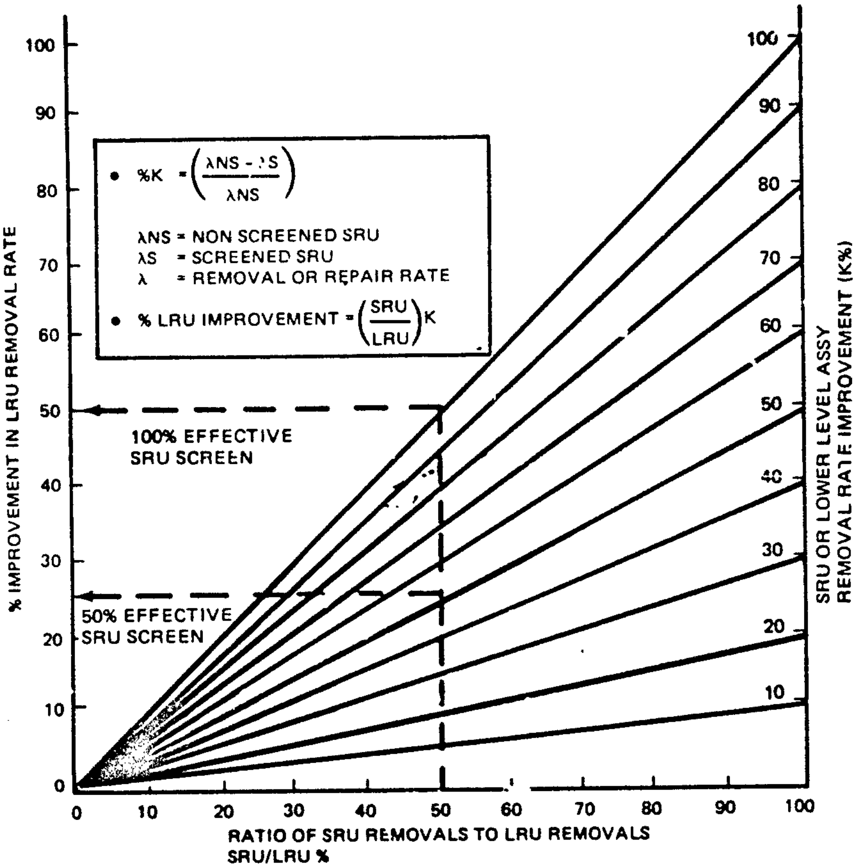

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Figure C-4. Improvement in LRU removal rate as a function of SRU removal rate contribution.

For these reasons, unless it can be justified (based on the graph of Fig. C-4) that the rate of impact at a lower level of assembly will have an impact at the LRU level, there is no gain that can be realized by screening the lower level of assembly.

A candidate SRU should be selected from the list of LRUs developed in Subsection 4.1.1.2. A rank priority list of these SRUs should be prepared by the cognizant ALC. The percentage of repairs performed on the SRU in relation to all the SRU repairs performed against the LRU should provide the percentage weight for SRU consideration.

$$\frac{SRU_i \text{ Repairs}}{\text{Total SRU Repairs per LRU}} \times 100 = \% \text{ SRU}_i \text{ contribution}$$

This percentage is the ratio that could be used in Fig. C-4 in lieu of the removal rate ratio. The frequency of repair data for the SRU will be developed from the ALC repair data bases.

4.1.1.4 Lower Levels of Assembly Selection - Without a complete, detailed operational history of all typical parts and lower levels of assembly, there is no basis of selection of lower levels of assembly for testing in the field. Testing at this level should be performed at a supplier or vendor facility, so as to screen (as an in-process function) logistically supplied material that will enter previously screened higher order assemblies (LRUs or SRUs). Any consideration of screening existing stocks of lower levels of assembly should be closely cost evaluated. Lower levels of assembly include hybrids, Integrated Circuits (ICs) and assorted piece parts. The basis for selection and screening at these levels may be in accordance with DOD-HDBK-344 (USAF). Once again, the basis for traceability shall be the candidate LRUs.

4.2 SELECTION CRITERIA

The selection criteria will be applied to the candidate population of high removal LRUs selected in Subsection 4.1.1.2, to provide an optimal selection basis which will further minimize and eliminate hardware which will not be ESS sensitive.

4.2.1 Qualitative Criteria

Qualitative criteria shall assess the physical and design attributes of the hardware, and will require the application of engineering judgement, and design and logistic support knowledge of the hardware to support decisions to continue. Qualitative factors to be considered include:

- Functional Testability - effective ESS requires functional verification during and after testing
  - Special Test Equipment (e.g., ATE) and loading demands
  - Use of smaller, limited range, field type testers
- Previously ESS Tested LRUs - ESS testing affects design service life; multiple testing of the same units can be destructive
- Environmental Testability - state of the art in facilities and equipment availability may be a limiting factor in handling the test article; need to evaluate:

- Instrumentation requirements
- Weight of unit
- Size of unit
- Chamber capacities and rates of change
- Vibration table and surface capacity

- Level of Repair - test repairables only; non-repairables should be tested as procured, preferably at the vendor's facility
- Fixture and Mounting Design - fixture and mounting designs should be universal. Special purpose designs for specific hardware applications could be expensive
- Logistic Availability - ESS testing will stimulate failures at higher rates than normal. Any special repair requirements and considerations (e.g., out of production status) could be expensive, and could create unplanned demands (e.g., hardware that never failed before may start failing)
- Service Life - ESS testing will affect service life from both an effective yield and cost benefit potential point of view, and has the potential of being a destructive test. Note; successful ESS does not extend service life
- Configuration Control - multiple configurations, component interchangeability levels, functional variations, lot homogeneity and mixed requirements can create wide variations in testability for the same type hardware
- Warranty Commitments - ESS at an ALC may affect any contractual warranties; considerations may be to perform ESS on bad actors as part of warranty
- Ccmmercial Grade Hardware - commercial grade hardware is testable, however, failure and warranty responsibility may be a problem
- Vintage Design - qual levels may require extensive tailoring, to the extent that ESS profile is ineffective or potentially destructive.

4.2.2 Quantitative Criteria

Candidate LRUs should have a Discrimination Ratio (DR) of specified MTBF(s) to actual removal rate, MTBR, of greater than one:

$$DR = \frac{MTBF(s)}{MTBR} = >1$$

MTBF(s) is the design or operational objective, as defined by handbook predicting techniques (e.g., MIL-HDBK-217), specified contractual goals (e.g., warranties), field operational objective (e.g., R&M 2000 targets), or logistic planning goals (e.g., wartime loading levels) and should be expressed or factored in the time variables of the operating system (e.g., flight hours, operating hours, etc). The actual measured rate, expressed as the MTBR, is the system or equipment operating time parameter divided by the total removals.

This relationship will have more significance with non-aircraft type systems and low density (one of a kind) production systems. The measurements of MTBF or MTBR will then provide the probable departure from the specified value, and are really the only indication that workmanship defects may exist. The operating time parameters should be either the recorded operating hours of the unit or system, or duty cycle weighted in service hours. As an example, if the ownership time is one year, that would be a total of 8760 hours (365 days/year x 24 hours/days). If the operational duty cycle of the unit or system is eight hours per day, then the effective operating time would be 2920 hours (1/3 x 8760). This, divided by the reported removals or failures for the period, provides the measured MTBR value to be compared in the discrimination ratio.

4.2.3 Bad Actor Selection Criteria

In establishing a bad actors program, the objective is to minimize the number of units that should be tested, and identify only those units which will provide the most potential benefit from an ESS effectiveness point of view. These units will have a higher frequency of removals than the norm, usually in the form of false alarms or cannot duplicate conditions, implying the potential for intermittent conditions. The serialization process of LRUs as reported in the D056 database provides the means for identifying and determining the distribution of removals on a per unit basis. The process for establishing bad actors is shown in Fig. C-5.

4.2.3.1 Establishing a Process Average (μ) - The process average (μ), or the average number of defects per unit per period of time is expressed as the ratio:

$$\mu = \frac{\text{Total Removals per Period}}{\text{Number of Units Reporting per Period}} = \frac{R}{N}$$

Ⓐ

LRU S/NO. RANK (n)	LRU SERIAL NO.	TOTAL REMOVALS R
1	HGE-33	11
2	CSS-16	8
3	CSS-122	6
4	CSS-90	5
5	GRV-93	5
65		2
66		2
67		2
68		2
69		1
232		1
233		1
234		1
235		1
236		1
		345

"BAD ACTOR" DISTRIBUTION

GOOD UNIT DISTRIBUTION

(1) PROCESS AVERAGE (μ) $= \frac{R}{N} = \frac{345}{236} = 1.5$ RMVLS/UNIT

- NO. SYSTEMS REPORTING (N) = 236
- NO. UNITS PER SYSTEM (K) = 1
- NO. UNITS REPORTING (NK) = 236
- ACTUAL NO. UNITS REPORTING (n) = 236
- TOTAL REMOVALS (R) = 345

(2) DEFECT CRITERIA (D)

$D > \mu = D > 1.5 = 2.0$

RANK FREQUENCY DISTRIBUTION Ⓑ

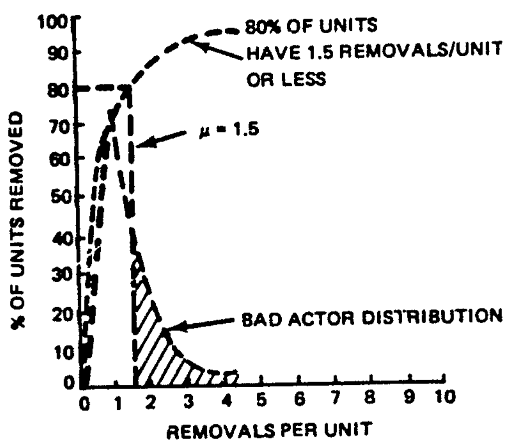

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Figure C-5. Bad actor selection.

or $\mu = \frac{R}{n.k}$

where: R = the total removals

n = number of weapon systems reporting

k = number of like units per weapon system

and $(n.k) \leq N$, which represents the minimum number of units that should be reporting (whether they have removals or not).

The value (n.k) represents the least number of units that should be reporting in the period (T) in contrast to the actual number of units (N). In Fig. C-5, the number of weapon systems reporting is n = 236, and the number of units per system is k = 1; therefore n.k = (236) (1) = 236.

- The actual number of units reporting (N) = 236
- The total removals (R) for the period (1 year) = 345
- The process average $\mu = \frac{345}{236} = 1.5$

From the frequency distribution, Fig. C-5 (B), it is seen that 80% of all units are 1.5 defects per unit or less. This means that 189 units (0.80 x 236) are at the process average or less. The remaining units (236-189=47) will be greater than the process average.

4.2.3.2 Rank Serialized LRUs - Ranking the serial numbers reporting by the number of removals reported per serial number (top down) identifies the units falling above and below the process average. Essentially, as shown in Figure C-5 all units with two or more removals (D = 2) are in excess of the process average (μ = 1.5). This identifies serial number 68 and above as the high contributors.

4.2.3.3 Establish Defect Criteria - The defect criteria (D) is the real removal value or greater that exceeds the process average (μ) to the next highest whole value:

$D > \mu$ = unit bad actors frequency

In Fig. C-5, the value is:

$D > \mu = D > 1.5 = 2.0$

The number of units with two defects per unit per year or more is 68; or 68/236 = 29%. This group would represent the most likely population of LRUs with the highest potential for ESS effectiveness.

4.2.3.4 Predicting Outcome - The process average (μ) and the number of LRUs that have (D) or greater defects can be used to anticipate or project a potential improvement rate assuming that the defective process average (μ_D) will effectively achieve or approach the good process average (μ_G) as a result of effective ESS. The percent gain would then be:

$$\% \text{ gain} = \frac{\mu - \mu_G}{\mu} \times 100$$

When tested, defective units of process average (μ_D) will improve to achieve or approach the good process average μ_G, and the overall process average will at least approach $\mu => \mu_G$.

To demonstrate this, consider again the illustration in Fig. C-5. The data from the rankings is tabulated below:

	No. Units	No. Removals	Process Average μ
Defective (D)	68	177	2.6
Good (G)	168	168	1.0
	236	345	1.5

The defective process average μ_D = 2.6, the good process average μ_G = 1.0, and by testing the 68 units it is expected that $\mu_D \rightarrow \mu_G \rightarrow 1.0$. This will result in an overall process average $\mu \rightarrow \mu_G \rightarrow 1.0$. The percent gain potential is therefore:

$$\% \text{ Gain} = \frac{1.5 - 1.0}{1.5} = 33\%$$

or the rate improvement factor is 1.3 (the operational MTBR could improve by a 1.3 factor).

4.2.4 LRU Age

Experience with LRU age, in terms of years of service and the potential effects of ESS, does not exist to any formal degree or with sufficient background to support decisions one way or the other. Factors affecting LRU age include aspects of growth as a result of years of reliability improvement and upgrading, as well as degradation as a result of extended use and potential wearout. These factors must be counterbalanced to rationalize the potential effect from ESS which in one case can significantly improve the reliability of the device, and another case, degrade it in that it can potentially be destructive to the equipment. Although reliability may improve, ESS does not improve service life.

Grwoth extrapolations developed from non-ESS and ESS population performance, which together span some 15 years of compiled data, have concluded a generic curve as depicted in Fig. C-6. It is derived from a weighted consideration of all the growth curves developed, both positive as well as negative, and describes the

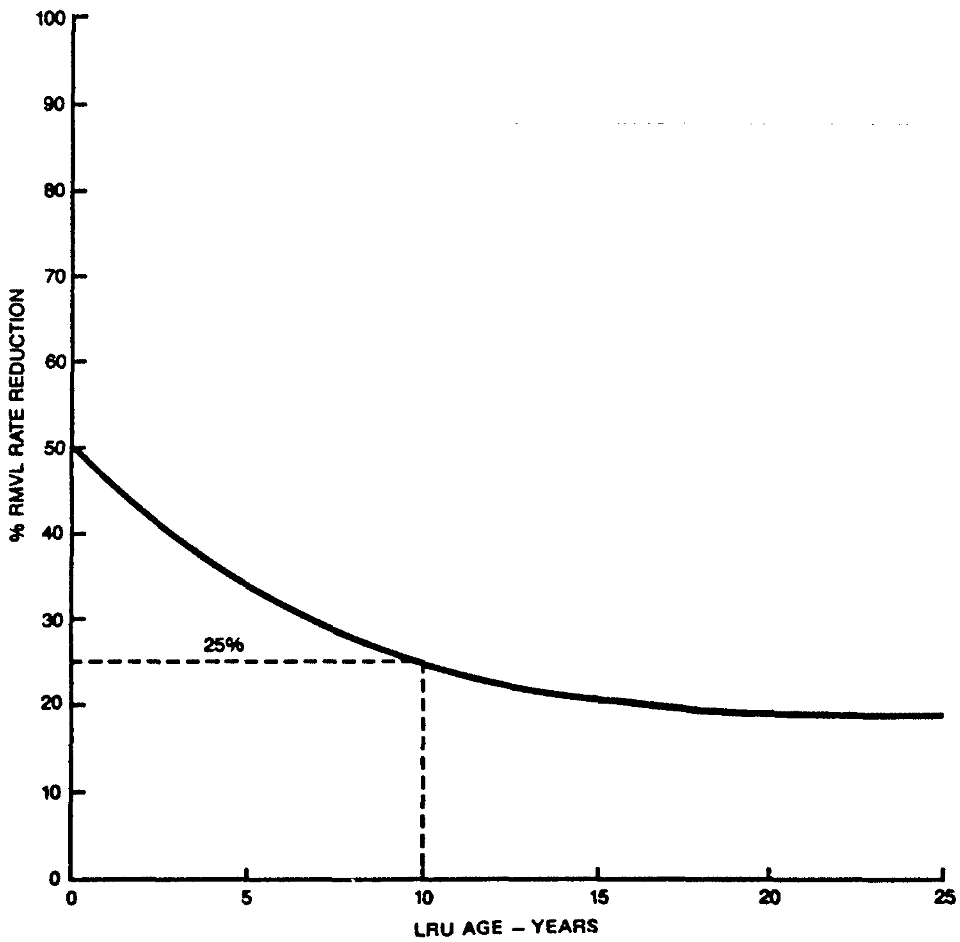

Figure C-6. Projected field ESS effects as a function of LRU age (years of service).

potential percent reduction in the total rate as a function of performing ESS on boxes having anywhere between 0 and 25 years of field life. Based on Fig. C-6, LRUs with an operational field service exceeding 10 years offer little in the way of improvement benefit due to ESS.

However, overhauled units which are refurbished for the purpose of extending life should be subjected to ESS irrespective of age. This will insure that reliability enhancements of refurbished components will be effective. Tailoring may be a factor in developing proper environmental profiles for these LRUs.

4.3 TEST PROFILE DEVELOPMENT

At this point in the ESS candidate selection process, the Air Force Item Manager has already completed the field data analysis (Section 2) and equipment selection criteria (Section 3). The next step is to determine the equipment level, i.e., LRU or SRU, to which the ESS testing will be applied, and also the specific environments necessary to stimulate the potential workmanship and manufacturing process problems. Figure C-7 describes the process to define the specific testing effort that will be estimated during the Final Cost Analysis described in Subsection 4.4.

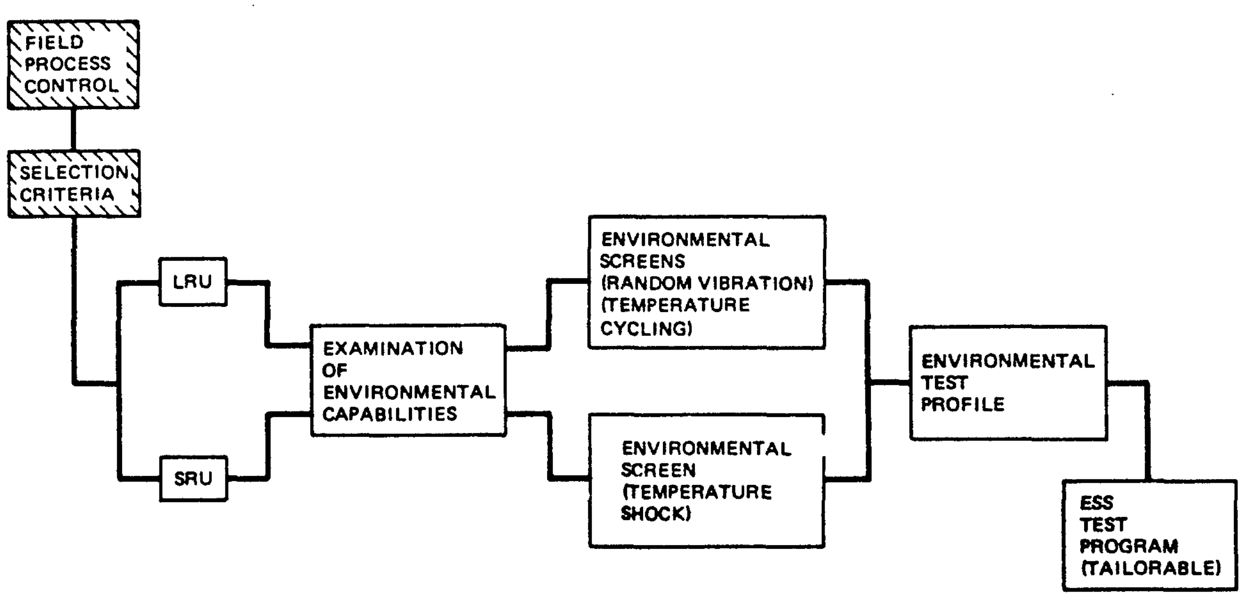

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Figure C-7. nvironmental test program flow.

During electronic equipment development programs, the equipment designer selects numerous environmental tests to evaluate the equipment's operational performance at its lower levels of assembly to determine as early as possible whether there are any potential design, manufacturing, process and/or any workmanship problems. It is crucial at that time to ascertain that the purchased parts and the subassembly designs, when assembled, meet the design's predicted environmental criteria. This environmental test verification phase in the equipment's development is very cost effective because it exposes design problems when there is still the opportunity to resolve them. At that time, the current experts of all the technical communities will be familiar with the design and easily resolve any problem. When satisfied with the design, all further acceptance testing is at the highest level of assembly, the LRU.

Once the LRU is delivered to the customer, any delta ESS to verify field corrective action should continue at that level. It is at this level of assembly that the required support equipment is already designed and manufactured, permitting complete operational diagnosis of any LRU performance parameters and thus minimizing test time and costs. Fully operational LRU ESS installations are mandatory because approximately 50% of all workmanship related problems are of an intermittent nature.

4.3.1 Environmental Characteristics

The next step in the ESS process prior to conducting any environmental tests on the candidate equipment is to determine the environmental characteristics. Research is required to obtain data on the equipment's environmental qualification tests results, including any environmental acceptance tests levels and the operational data describing the vehicle environment in which the equipment is currently installed.

4.3.2 ESS Profile

Since these guidelines are directed towards Government Furnished Equipment (GFE), non-ESS field electronics which are normally repaired at a depot, it is advantageous to utilize a generic ESS profile. This approach simplifies the ESS test operations, reduces equipment costs, and minimizes the ESS familiarization and training requirements. Thus we recommend using the ESS requirements and procedures

defined in MIL-STD-2164 (EC). This document is based on generic test levels and durations developed for space, aircraft, and shipboard electronics. The consistent utilization of these requirements has proven that, in most electronic equipment designs, there is a minimum structural rigidity existing within the pre-1980 designs which represents the major number of electronic equipment in the field today. It has been shown that equipment, though never exposed to random vibration, has demonstrated the required structural and electronic integrity to be inherent within the design. Thus the only problems that should appear during ESS testing are those directly associated with workmanship and/or manufacturing process.

4.3.3 LRU ESS Requirements

The total ESS program includes physical inspection, functional tests, and periods of environmental exposure designed to stimulate latent defects without incurring equipment fatigue damage. Figure C-8 presents the overall test flow that will be used to verify that an equipment is ready for operational use.

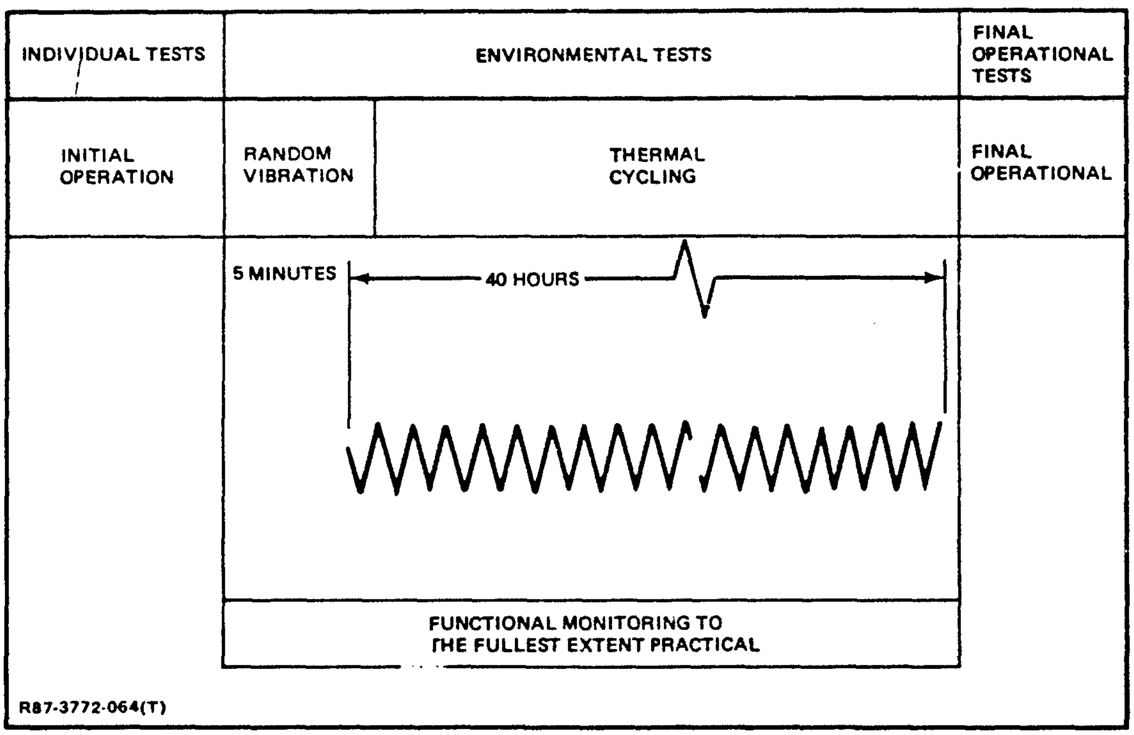


Figure C-8 ESS test sequence.

4.3.3.1 Individual Tests - Each equipment under test will be subjected to:

- Initial Operational Test - an equipment operational test in accordance with the seller-prepared test procedure will be performed, and data will be recorded to verify that the equipment fully complies with detailed performance requirements. The test procedure will include measurements required for a quantitative assessment of all functional performance parameters. GO/NO GO evaluation is acceptable. The record for pretest data will be retained for use as a reference during subsequent ESS tests
- Environmental Test - equipment submitted for test will be subjected to a fixed duration ESS test. The operational equipment will be continuously monitored, and all functional parameters will be exercised repeatedly at the highest attainable rate. The mechanization of the functional check-out and its speed of repeatability will represent a major task in the overall formulation of the ESS test program. All vibration testing will be conducted with the equipment hard-mounted, regardless of whether or not it is to be installed on vibration isolators in its use environment.

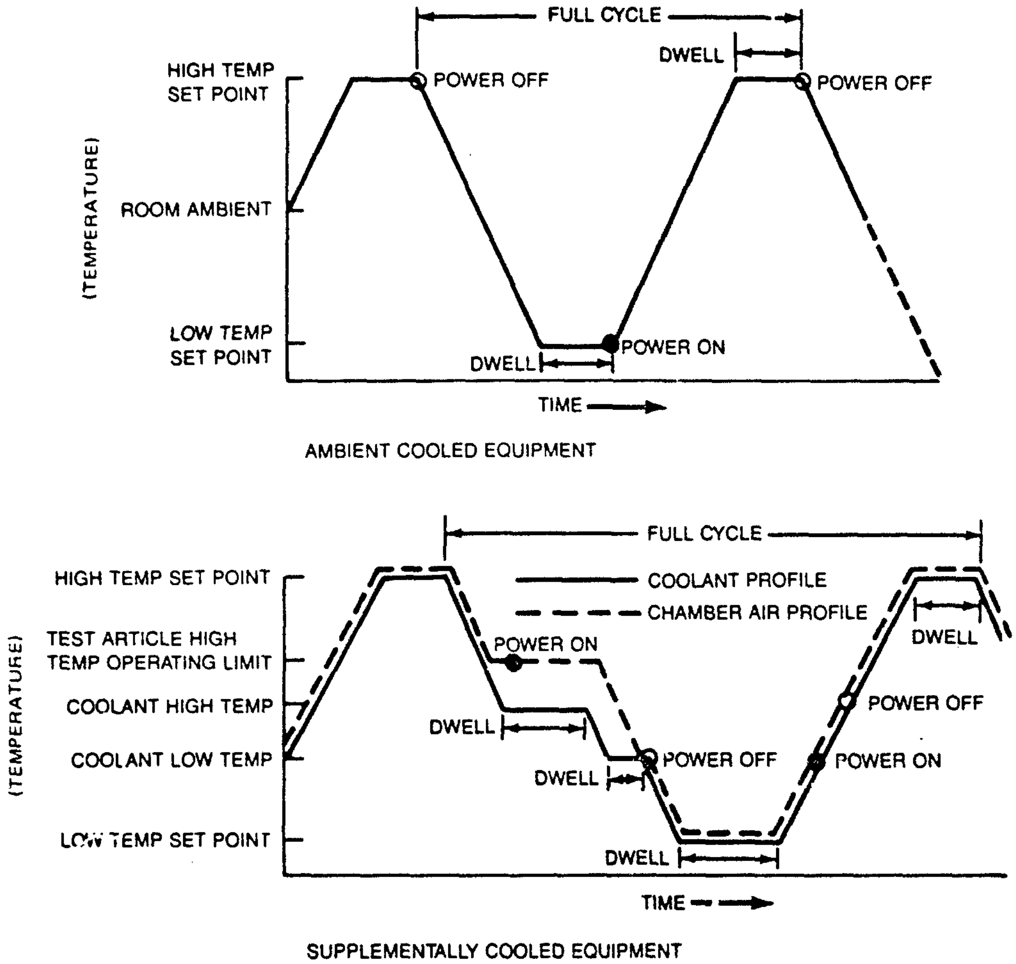
  Each equipment will be exposed to random vibration and thermal cycling periods (Fig. C-8). Since the purpose of this test is to eliminate latent manufacturing defects, all defects detected during this test will be recorded and repaired

  Note: Since this testing is directed to in-service GFE, exposed to numerous environmentally operational hours, the need for a fixed ESS failure-free period is not necessary. Thus as long as each ESS related problem is corrected when it occurs, it is expected that at the completion of the fixed during ESS periods there will be a justifiable amount of failure-free operation
- Vibration - the equipment in an operating mode (power on) will be exposed to one five minute burst of random vibration in the axis deemed most susceptible to vibratory excitation. Failures occurring during this five minute test will be corrected as they occur. The random vibration spectrum will be:

  20-80 Hz at 3 dB/octave rise

  80-350 Hz at $0.04g^2/Hz$

  350-2000 Hz at 3 dB/octave rolloff
- Thermal Cycling - the equipment in an operating mode (power on) will be subjected to a thermal cycling test for a period of 40 hours in accordance with the appropriate cycle (Fig. C-9). The required number of thermal



NOTES:

1. RATE OF CHANGE OF TEMPERATURE SHALL BE 5°C (9°F)/MINUTE

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Figure C-9. Temperature cycling profile for ambient cooled & supplementally cooled equipment.

cycles should be interrupted for each repair action. The thermal limits (high and low temperature extremes of chamber air) for cycling will be those values of operational temperature requirements defined by the equipment specification.

4.3.3.2 Final Functional Operational Test - Upon successful completion of the environmental testing, a final functional test will be performed at room ambient conditions to verify satisfactory operation of the equipment in accordance with the parameters specified in the prime item specification. Operational measurements will be compared with those obtained during the initial operational test and evaluated based upon the specified acceptable functional limits.

4.3.4 SRU ESS Requirements

ESS testing of SRUs should be limited to spares and those items which have experienced high failure rates in the operational environment. For those situations, no ESS testing should be imposed across the board. When necessary, the optimum environmental test should be a non-operating thermal shock for a period of 25 repetitive cycles. The maximum transfer time should be one minute or less and the soak periods approximately one hour each. The temperature extremes should be based on the maximum, not operating, temperature qualification level. Only those assemblies which are known problem installations should be ESS tested. If a spares manufacturer is producing a good product, which indicates his workmanship is good, the manufacturer should not be burdened with additional costly requirements. Test efforts should concentrate on the "bad" products.

4.3.5 ESS Tailoring

In the case of inventoried equipment, consideration must be given to the environmental capabilities of the ESS candidate equipment. The probability exists that this equipment may not have been designed to function in a generically defined random vibration or rapid thermal cycling environment. Thus some form of environmental tailoring is required. It should be pointed out that experience has taught us that this does not mean the subject equipment is incapable of withstanding the latter environment. In most cases this same equipment probably has been operating successfully in a similar environment, i.e., in a jet aircraft experiencing rapid temperature changes and random vibration without any structural damage. The only potential problem for some equipment was that when the generic ESS levels were applied, performance anomalies (such as out of tolerance conditions) became evident.

In order to accommodate this situation, ESS levels must be tailored by notching the random vibration spectrum at the primary LRU resonances. For this vibration notching, accelerometers must be installed at selected items within the equipment and a series of low level sinusoidal sweeps performed to define resonance.

After instrumenting these test units, it became apparent that if the response acceleration exceeded an amplification factor of 10, a potential performance problem would become evident. In these instances it was necessary to tailor the random vibration levels by notching certain frequencies to minimize the operational problems associated with marginal component or subassembly installation.

A successful technique during tailoring is to install adequate instrumentation on the test article to record the amplification factors measuring a potentially sensitive component installation, during a ±3.0g sinusoidal sweep from 20 to 2000 Hz. At those resonances where the amplification exceeds 10, random spectrum notching is performed to reduce the input to the equipment. An example of this technique is as follows:

(1) Conduct a ±3g sine sweep and measure the ratio (response/control) at the desired locations (see Fig. C-10 for typical response)

VIBRATION SURVEY RUN 8Z-3G SINE SWEEP – TRANSMISSIBILITY PLOT OF ACC 9 – A3000 TRAY IN Z AXIS

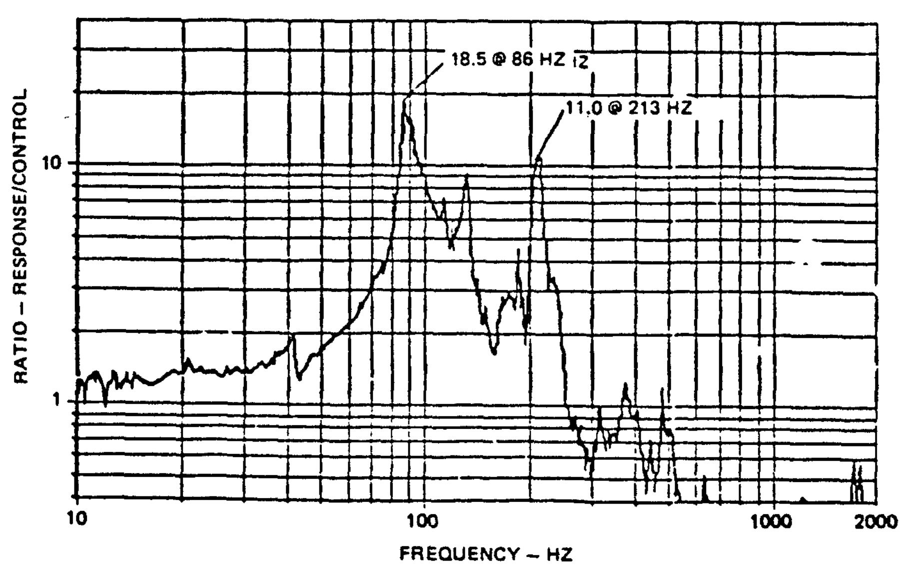

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Figure C-10. Typical ± 3g sine sweep response.

(2) Record measured vibration amplification factors exceeding 10:

Acc No.	Location	Ampl-3G Inp
1	Bottom of A1000 assembly	11 @ 104 Hz
3	A4000 Tray	16 @ 104 Hz
9	A3000 Tray	15 @ 80 Hz
10	A8000 Tray	20 @ 100 Hz
13	Top of A8000 assembly	16 @ 103 Hz
7	A5000 assembly	10 @ 196 Hz

(3) Perform random vibration notching to reduce amplifications to 10:

79 to 95 Hz - Max Ampl = 15 PSD = (10/15) x .04 = .0267 GSQD/Hz

95 to 104 Hz - Max Ampl = 20 PSD = (10/20) x .04 = .0200 GSQD/Hz

104 to 113 Hz - Max Ampl = 14 PSD = (10/14) x .04 = .0286 GSQD/Hz

Above 113 Hz No notching done in this freq range.

(4) Incorporate notching on the generic 6.0g RMS random vibration test spectrum as follows in Fig. C-11:

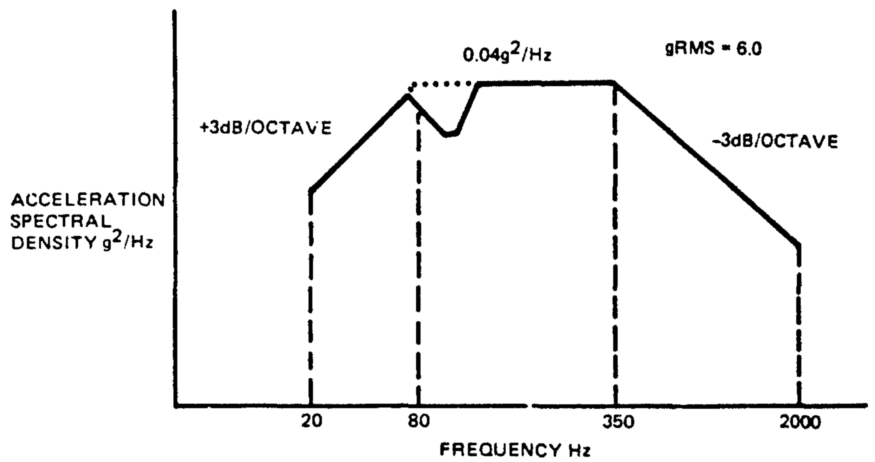

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Figure C-11. Notching on 6.0g RMS random vibration test spectrum.

With respect to tailoring the rapid thermal cycling requirements, the tempera-ure extremes were selected based on the equipment's operational environmental ualification limits. It was also determined that, at the LRU level, there was not ny advantage to exceeding the 5°C/minute rate of change.

What we did see in our field equipment ESS investigations indicated there was ittle advantage to performing both a 40 hour pre-defect free and a 40 hour defect ree thermal cycling test. The test data indicated that the problems which the

previous use environment stimulated were the major workmanship and manufacturing problems, thus negating the need to do a pre-defect period. It was thus decided that if the candidate equipment experienced an ESS failure during thermal cycling and was replaced immediately after that cycle, there should be an adequate number of defect free cycles accrued within the fixed 40 hour period. This considerably reduces the test time and associated costs.

4.3.6 Generic ESS Test Recommendations

ESS tests of contract end items consisting of electronic components and subassemblies should be subjected to the rapid thermal cycling and random vibration defined in MIL-STD-2164(EC). The objective of these tests is to stimulate early occurrence of workmanship and manufacturing process problems so that corrective action can be addressed prior to delivery of the procuring activity.

During the specified random vibration and rapid thermal cycling tests, it is mandatory that the equipment be operated and monitored to the fullest extent possible, except during the down portion of the thermal cycle. It should be noted that the equipment will experience the required thermal stresses from the removal of equipment power and the rapid descent of the temperature chamber.

Random Vibration	Equipment, Box, or Drawer (LRU/LRM)
• Power spectral density	20-80 Hz @ +3dB/Octave 80-350 Hz @ .04 g^2/Hz 350-2000 Hz @ -3dB/Octave
• Axes stimulated	One axis perpendicular to the printed wiring board
• Duration of vibration	5 min at start of test
• Power on/(equipment operation)	Yes
• Equipment monitoring	Yes
Thermal Cycling	
• Temperature range	Operating environmental qualification limits
• Temperature rate of change	5^{o}C/min
• Temperature dwell duration	Based on thermal signature study

- Thermal cycling duration — 40 hours
- Power on/(equipment operating) — Yes
- Equipment monitoring — Yes
- Electrical testing after ESS — Yes @ room ambient

4.4 ECONOMIC SELECTION CRITERIA

The cost benefit will be based on the financial return when money, time, and effort is invested to perform the ESS, and the resulting annualized ROI is at least 33-1/3%. The equation in Fig. C-12 defines the economic elements required to perform the analysis and develop projected cost savings and ROI. Each LRU candidate selected for field ESS should be cost benefit evaluated to support test justification. The task methodology for this process is shown in Fig. C-13. Although the methodology for determining the cost is applicable to any level of assembly, i.e., LRU, SRU, and subassembly, it is recommended that cost justification be rationalized at the LRU level, since significant net cost savings and ROI become more difficult to achieve because of lower unit cost levels and higher element MTBF values. If the improvement and ROI cannot be significantly rationalized at an LRU level, it is probably not worth considering.

4.4.1 Logistics Support Cost Savings (LSCS)

The LSCS is expressed as:

$$LSCS = LSC_o - LSC_p$$

where:

(1) LSC_o - Baseline logistic support cost is the current operational LSC of the LRU at the time of selection

(2) LSC_p - The projected LSC that will be realized as a result of the removal rate improvement.

The LSC analyses should be performed with the models and scenarios developed for the specific weapon system (e.g., fighter aircraft, transport, stationary ground, mobile ground) from which the LRU is being selected.

4.4.1.1 LSCS Estimating - For estimating purposes, Fig. C-14 is provided. The LSCS factor is read directly as a function of the current operational removal rate per month for the specific LRU, as obtained from the maintenance data, and the projected rate improvement either as a direct input from Subsection 4.1.1.4 or adjusted

$$ROI\% = \frac{(LSCS) - ((AFC) + (DTC))}{((AFC) + (DTC)) \bullet (SL - EA)} X 100 \geq 33\ 1/3\%$$

WHERE: (1) LSCS = LOGISTICS SUPPORT COST SAVINGS

(2) (AFC + DTC) = TEST IMPLEMENTATION COST

- AFC = AMORTIZED FAULITY COST (NON-RECURRING)
- DTC = DIRECT TEST COST (RECURRING)

(3) [(LSCS) − (AFC + DTC)] = NET COST SAVINGS

(4) (SL - EA) = REMAINING SERVICE LIFE

- SL = DESIGN SERVICE LIFE
- EA = EQUIPMENT AGE AT THE TIME ESS IS PERFORMED'

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Figure C-12. ESS ROI formulation.

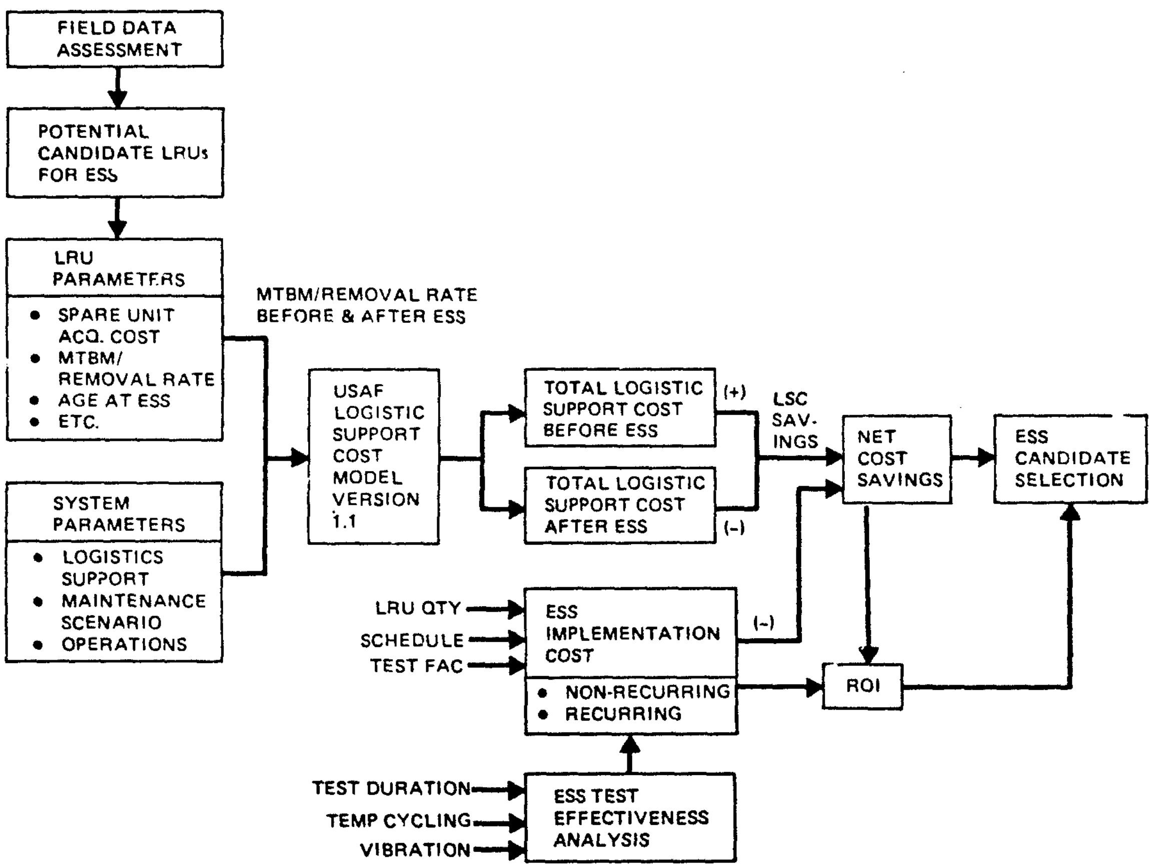

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Figure C-13. Procedure for economic analysis.

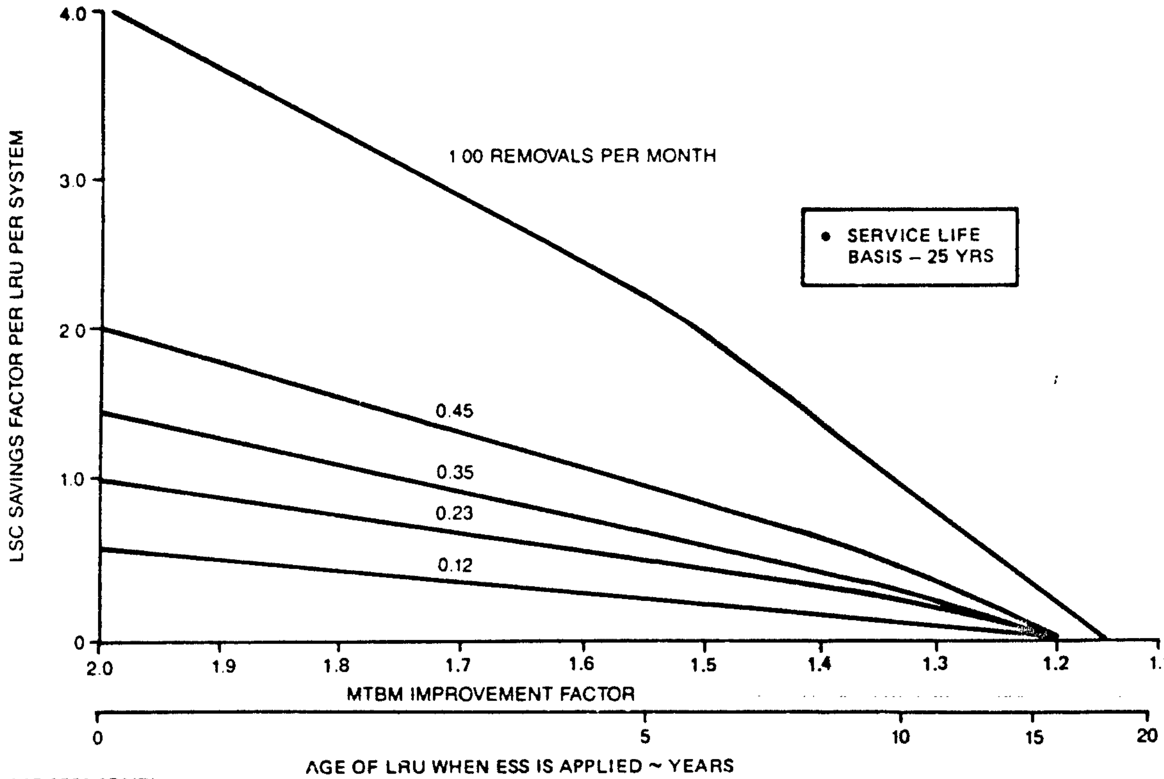

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Figure C-14. Projected field ESS logistic support cost savings factor vs MTBM improvement factor.

as a function of the average equipment age at the time of selection (equipment age is defined as the average age of the population of candidate LRUs). The LSCS factor is then multiplied by the LRU unit spares acquisition cost to provide the estimated LSCS dollars:

LSCS (Factor) x Unit Cost = LSCS

Removals per month greater than one are almost virtual candidates, however, caution and engineering judgement should be exercised when the age of equipment starts to exceed 10 years. Exceptions are for units that are completely overhauled; where the chassis may exceed 10 years, but the lower level SRUs and assemblies are new or refurbished.

4.4.2 Test Implementation Costs

Test implementation costs consist of non-recurring Amortized Facility Cost (AFC) and the recurring Direct Test Cost (DTC) and repair. These costs can nominally run between 7% and 9% of the Unit Cost (UC), AFC + DTC = (7-9%) • UC, and are dependent upon such criteria as:

- Test chamber and equipment cost
- Test duration
- Number of units in flow
- Number of test programs being managed by AFC
- Cost of labor to perform tests
- Cost of repairs of failures encountered during test
- Cost of spares to support repair
- Cost of additional support equipment to support functional testing.

4.4.2.1 Amortized Facility Cost (AFC) - The non-recurring amortized facility cost is principally driven by the cost of test equipment and set-up and effective test management to maximize facility use within the constraints of test duration and unit flow capacity. This cost may be expressed as:

$$AFC = \frac{(t)\ (n)\ (c)}{(T)\ (N)\ (K)} = \text{Cost per Test Unit (LRU/SRU)}$$

where:

t = test duration required per unit

T = number of available test hours per month per set of test equipment

n = LRUs/SRUs per month to be tested

N = total number of LRUs/SRUs to be tested

c = cost per test equipment set-up (temperature, chamber, and vibration equipment)

K = number of different test programs to be implemented.

Reducing the number of test equipment set-ups (temperature chambers, vibration equipment, and peripherals) to optimize the test unit flow is a major impact. Factors to be considered include:

- Vibration equipment is only required approximately 10 minutes out of every 40 hours of testing, representing only 8% of the cycle time, and would therefore require perhaps one vibration system for every five to ten temperature chambers

- Vibration equipment normally represents approximately 65% of a single test set-up cost. Therefore minimizing the number of vibration systems is significant in any amortized facility set-up
- Test fixtures and mounting devices should be as universal as possible. Requiring new set-ups for each different type of LRU/SRU to be tested will be costly and create delays for set-up.

4.4.2.2 Direct Test & Repair Cost (DTC) - Recurring test and repair costs, or the costs to physically perform the screening tests, is based on the repair per unit as a function of the logistics support cost of the LRU/SRU to be tested. Recurring costs include:

- Labor to perform tests
- Labor to perform functional tests
- Repairs for failures encountered during test
- Spares to support repair
- Shipping and handling test units.

These are costs that can be developed as a function of the logistic support cost for the unit under test. Taking the logistic support cost of the unit as developed in Subsection 4.4.1 and dividing by the total expected number of repairs over the life cycle (as a function of unit utilization, expected service life, and operational failure rate) provides the average cost per repair.

The number of failures or repairs to be encountered during the testing is a function of the process average μ as defined in Subsection 4.2.3. This would be the average number of defects that can be expected per unit. The direct test cost therefore is expressed as:

$$\text{DTC} = \frac{\text{LSC}}{\begin{array}{c}\text{Total Service}\\ \text{Life Repairs}\end{array}} \times \mu = \text{cost/unit tested}$$

Figure C-15 provides the DTC as a function of the repair cost/unit and varying process averages.

4.4.3 Comparative ROI

Comparative ROI will provide the indications for economic candidate selection when all the variables of age, test duration, level of test, unit flow, rate improvement, etc have been considered. The ROI outcome in each case should be at least

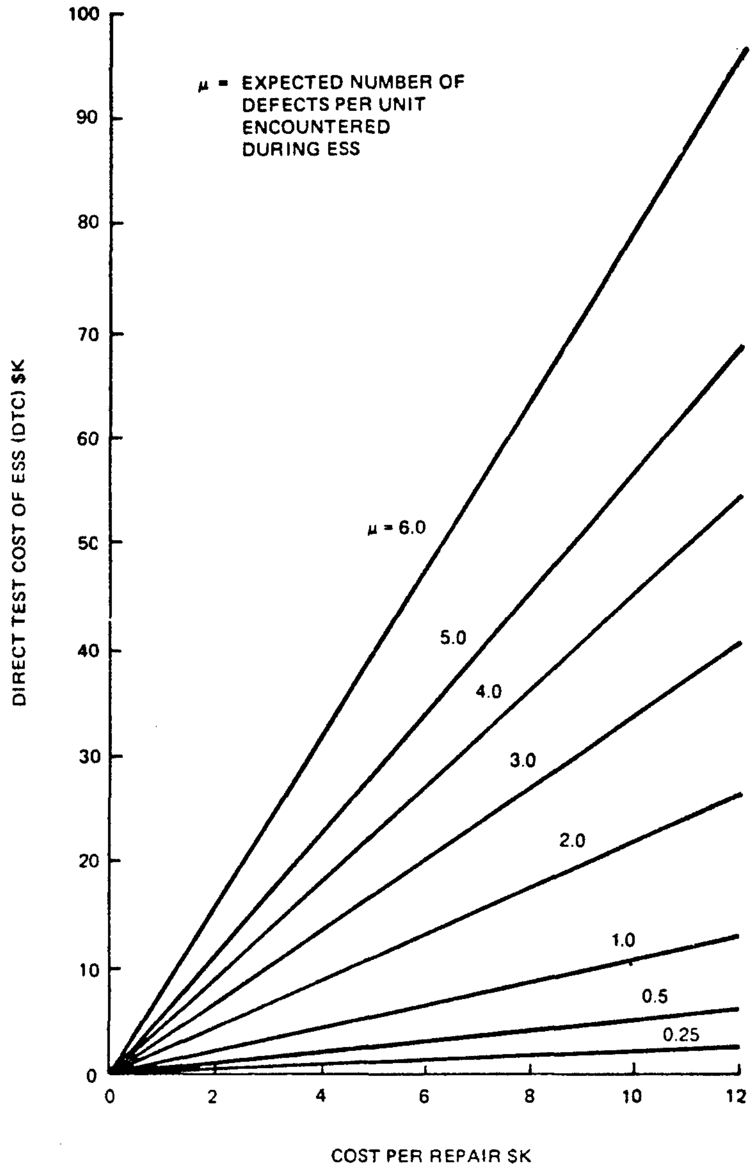

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Figure C-15. Direct test cost as a function of cost per repair cost & process average (μ).

33-1/3% or greater to support cost justification. Table C-1 and Fig. C-16 provide the typical comparative analysis illustration to support justification of economic selection of ranked LRUs. Estimates of potential removal rate improvement (MFHBM without ESS vs MFHBM w/ESS) provide the basis of logistic support savings. This can be accomplished parametrically using Fig. C-15 which projects up to a 2:1 potential improvement in removal rate, or by projecting the outcome as a function of the bad actor distribution as defined in Subsection 4.2.3.4. The graphic comparisons (Fig. C-16) assess the variation in the ROI as a function of the efficiency of the test program, that is, the percentage of defects that are reduced and the test duration. The graphics show defect yield rates of 100%; 50% and 25%, considering the test duration of 120 or 40 hours, which are the extremes per MIL-STD-2164(ES), as well as the age of the LRU at time of testing. Irrespective of test duration, as the potential gain in removal rate is reduced, the number of economically viable units significantly reduces (ROI drops below 33%). The most economical combination is produced by the reduced test duration with a reduction in the number of units to be tested, while retaining a high potential for defect reduction, such as with the case with the selection of bad actors. Optimally the selection should consider:

- High removal rate LRU contribution, within the top 25 ranking of the weapon system (lower levels are not cost effective)
  - SRUs drawn from these LRUs for testing should represent at least 25% of the total removal rate/or repair rate of the LRU
  - Lower levels of assembly should not be considered for field selection (these should be tested as procured)
- Select LRU testing priority based on bad actor selection criteria. This offers the opportunity to test the least number of units and achieve the optimal improvement level which is economically the most significant
- Equipment with over 10 years of service life at the time of evaluation offers little in the way of cost benefit, unless:
  - Removal rate impact is significant, greater than 25% of the weapon system removal rate
  - Unit is being overhauled for service life extension. Note that replacement by new unit (manufacturer furnished) may be more cost effective
- For field screened hardware, eliminate the failure free portion of test as recommended in Subsection 4.3. This will reduce the test time by at least half and offers the opportunity to test more units in a shorter span of time.

TABLE C-1. ESS projected cost savings & ROI.

LRU	UNIT COST $	AGE AT ESS (YRS)	MFHBM W/O ESS	MFHBM W ESS	LSC SAVINGS FACTOR	LSC SAVINGS PER UNIT $	ESS IMPLEMENT COST $	NET SAVINGS PER UNIT $	COST SAVINGS RANK	ANNUAL RETURN ON INVESTM'T %
EXCITER (WUC 76M0) (MBE)	487000	0	30	60	4	1948000	41000	1907000	1	186
		1	30	57	3.6	1753200		1712200	2	174
		3	30	52	2.9	1412300		1371300	3	152
		5	30	46	2.2	1071400		1030400	4	125
		10	30	40	1	487000		446000	7	73
		15	30	37	0.3	146100		105100	22	26
RF CALIBRATOR (WUC 76ZP0) (RFC)	174000	0	67	134	2	348000	25200	322100	13	51
		1	67	128	1.8	313200		288000	14	48
		3	67	116	1.6	278400		253200	18	46
		5	67	104	1	174000		148800	21	30
		10	67	90	0.5	87000		61800	25	16
		15	67	82	0.1	17400		-7800	34	-3
RADAR IR INDICATOR (WUC 73BR0) (RIRI)	302000	0	85	170	1.4	422800	29600	393200	9	53
		1	85	162	1.3	392600		363000	11	51
		3	85	147	1	302000		272400	16	42
		5	85	131	0.7	211400		181800	19	31
		10	85	113	0.3	90600		61000	26	14
		15	85	104	0.1	30200		600	32	0
COMPUTER SYNC UNIT (WUC 76Y50) (CSU)	444000	0	85	176	1.4	621600	38000	583600	5	61
		1	85	168	1.3	577200		539200	6	59
		3	85	152	1	444000		406000	8	49
		5	85	136	0.7	310800		272800	15	36
		10	85	117	0.3	133200		95200	23	17
		15	85	108	0.1	44400		6400	31	2
SIGNAL DATA CONVTR (WUC 76Y20) (SDC)	401000	0	129	258	1	401000	27000	374000	10	55
		1	129	246	0.9	360900		333900	12	52
		3	129	223	0.7	280700		213700	17	43
		5	129	199	0.5	200500		253700	20	32
		10	129	172	0.3	120300		173500	24	23
		15	129	143	0	0		-2700	36	-10
DIG DATA DISPLAY (WUC 76Y10) (DDD)	116000	0	257	514	0.6	69600	12300	57300	27	19
		1	257	491	0.5	58000		45700	28	16
		3	257	445	0.4	46400		34100	29	13
		5	257	396	0.3	34800		22500	30	9
		10	257	342	0.1	11600		-700	33	0
		15	257	285	0	0		-12300	35	-10

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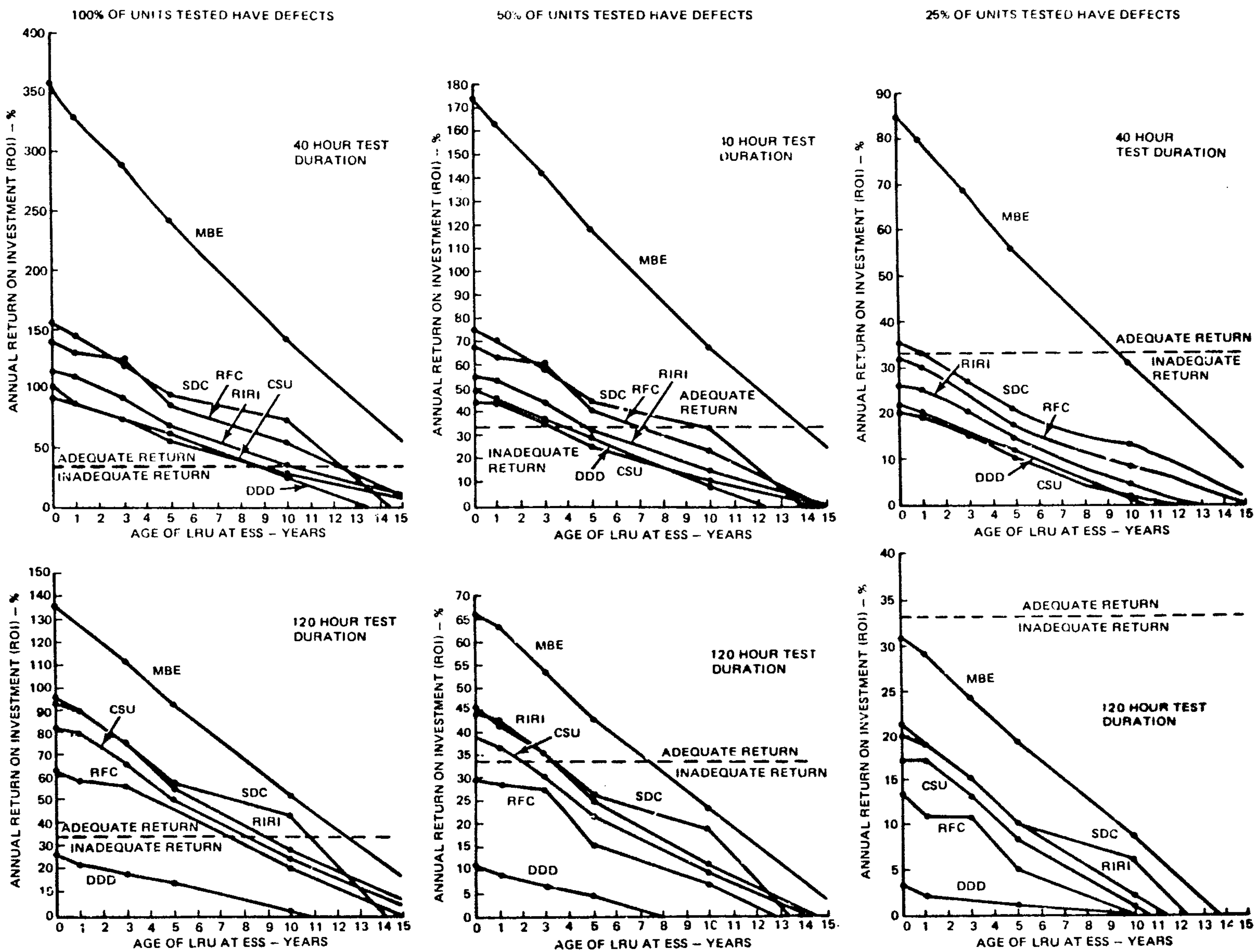

Figure C-16. ROI effect as a function of ESS test efficiency.

5 - DATA REQUIREMENTS

In support of selection process criteria, analysis, cost planning, and test plan development, the following equipment characteristic data field data management is required.

5.1 EQUIPMENT CHARACTERISTICS DATA

- Specified or Predicted MTBF - includes any operational or logistic goals that may be defined
- Environmental Design Levels - operational temperature and vibration levels to support assessment of tailoring requirements and insure that ESS levels are not design excessive
- Functional Performance Characteristic - to insure adequate functional performance integrity during screening, including test point and support equipment interface requirements
- Level of Repair Requirements - to identify maintenance policy planning including:
  - Repairability or non-repairability
  - Expected service life
  - Time to overhaul criteria
  - Level of assembly definition
  - Logistic planning
- Configuration & Age Data - to define system make-up and hardware application, identify:
  - Average number of units required per system to define full mission status
  - Configuration (if units are multisystem oriented, i.e., can be used in F15, B52, etc)
  - Number, age, and interchangeability of upgrades
  - LRU serial number blocking (by upgrade, if possible)
  - Average field service age of equipment to be considered for test
- Unit Spares Acquisition Cost - average unit spares acquisition price of unit in current year dollars

- ESS Status - if screened at a manufacturer's facility, as part of acceptance, provide:
  - Tested to what specification or standard
  - Environments applied and levels
  - Cycle durations
  - How applied, 100% sampling, random, etc
  - Identifiable serial numbers
- Warranty Criteria - to define potential limitation of field ESS and repair implementation, as well as possibility to use warranty to have suppliers provide ESS services and incentives.

2 MODAS/AFD056 DATABASE REQUIREMENTS

In support of candidate selection and monitoring in the field maintenance environment, maintenance removals and repair data should be reduced, otherwise programmed, and managed to provide:

- Ranking LRUs in WUC categories 5, 6, and 7; by total removals (Type 1 + Type 2 + Type 6). Note: this should exclude all 800 series How Mal Codes
- LRU serial number ranking by total removal
- Number of weapon systems reporting per period
- Number of serialized LRUs reporting per period
- Subcategorization of Type 1 actions
  - With Parts - with completion of "H" and "P" card data
  - Without Parts
- One year (12 month) moving process average μ (computed per Subsection 4.1.3); and distinguishing between μ_G and μ_D.
- SRU serialization or identification system
- ESS action taken codes for LRUs previously tested
- Coding system for identifying SRU units tested.

6 - IMPLEMENTATION OPTIONS

Once hardware types and levels have been selected, options for hardware collection, test management, and test locations should be as generic and standard as practical for the category of equipment selected. It should be remembered that the objective is to test the equipment only once, and to limit testing to only those units that offer the highest potential for reliability and readiness improvement at a reasonable ROI. This can only be accomplished by:

- Minimizing set-up and facility amortization costs by diversification and planning of facilities to handle several equipment types
- Minimizing cost and demands for additional and specialized support equipment
- Maximizing resources, material, and skills for rapid repair capability to preclude excessive testing, handling, and test interruption for lack of spares, materials, and poor repair practices
- Centralizing technical skills both for test and equipment under test to insure quick problem corrective action response, as well as standardization of test procedures, functional test parameters, and trouble-shooting methodology.

The option considerations include the following.

6.1 TESTING HARDWARE ON AN "AS REPAIRED" BASIS

This is screening performed on hardware only after it has been through the repair and return to inventory cycle. The testing becomes a one time extension of the repair cycle and offers the best cost options since it handles the equipment as it is in flow, minimizing the added support costs of the ESS test as well as the impact on hardware availability and turnaround time.

This should be considered when:

- It is concluded that a total population of units should be tested. In-service units that have not failed would not be tested
- Testing low production density systems, (e.g., ground equipment, radars, etc) so as to insure that equipment is always on-line

- Testing of repairable SRUs and lower levels of assembly that are identified as candidates. This will require a controlled identification system to identify previously tested units. In-service units that do not fail would not be tested
- Testing bad actors; these could be selectively pulled in the repair cycle based on their identification. They would more than likely be frequent visitors to the repair facility in a relatively short span of time. Non bad actor units would not be tested. This would, in effect, be a form of in-process sampling on a controlled basis.

! TESTING HARDWARE ON A "RECALL" PLAN

This is recalling hardware from the field on a scheduled basis, whether it has led or not. This effectively minimizes the test schedule impact, although test sts will accelerate due to the concentrated high demand on logistic material. This pe of planning should be considered when dealing with:

- High frequency problem units, preferably bad actors
- Units or systems that are scheduled for overhaul
- High readiness impact items that require scheduled inspections and tests, and require as short a downtime as possible because of demands
- High cost or high tech items where the set-up costs and planning are a problem.

3 TESTING HARDWARE FROM "READY FOR INVENTORY" STOCK

This is the pulling of previously repaired and accepted hardware that has been turned to stock and is awaiting further supply disposition. The major impact of is is the logistic support effect on existing field hardware. Pulling of good rdware from stock and environmentally testing them will probably require ditional repairs, creating logistic shortages and affecting system readiness. It so accelerates test costs, as well as field logistic costs. For these reasons, it ould only be considered on a planned scheduled basis to insure availability of ocks to support operationally deployed systems.

This would better be applied to lower levels of assembly that are stockpiled and e designated for 100% screening. This may be considered to upgrade stocks to be mpatible with new vendor delivered stocks that are screened at the manufacturer's cility.

6.4 ALC CENTRALIZED TEST FACILITY VS INTERMEDIATE MAINTENANCE TEST FACILITIES

For reasons enumerated in the introduction of this section, the optimal cost and technically effective approach to handling the enormous and diverse complexities of the equipment type, state of the art configuration, and performance criteria is to establish centralized ALCs that can handle the facilities, testing, and repair technology, and flow of the hardware. The use of intermediate test facilities (e.g., at tactical airbases) creates a massive decentralization control problem both in test technology and in identifying what equipment should be tested, as well as what has been tested. The effectiveness of ESS is not only the environment, but the planned process control that goes with it to insure end item continuity which bottom-lines the ROI (profit margin to a manufacturer).

The immediate problem is that the ALCs, in many cases, cannot handle large volumes of LRU level hardware; they are more geared to SRU level repair and testing. This requires some re-thinking of Air Force material maintenance management policies and planning, at least on a limited basis.

6.5 CONTRACTING FOR FACILITIES

The contracting of test facilities on a competitive basis can only be effective if it is adjunct to the requirements and control of the ALC, or is actually the manufacturer of the equipment to be tested. The contracted facility should not be purely a test laboratory but actually become a process control arm of the ALC, requiring the establishment of formal test planning and repair, and providing the skills and capability necessary to restore the equipment tested to a ready for inventory condition.

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